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An interactive virtual environment for training map-readings skill in helicopter pilots

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THESIS

AN INTERACTIVE VIRTUAL ENVIRONMENT FOR TRAINING MAP-READING SKILL IN HELICOPTER PILOTS

by

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September 1999

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Currently, Student Naval Aviators are trained to interpret 1:50,000 scale contour maps by watching VHS videotapes. These tapes show a helicopter moving about twice its normal speed over desert terrain. Primarily due to the lack of interactivity in these videos, students often make mistakes very early in the videotaped flight. The helicopter does not stop until the tape is over, hence, the training evolution quickly becomes useless because students usually make mistakes during the first minute of the tape and are unable to recover or to learn from those mistakes.

Based on a previous study at the Naval Postgraduate School, a training system that utilizes virtual environment technology was developed that is compliant with the Information for the 21st Century (IT-21) initiative. The system was built using a Windows NT / Intel (Wintel) based computer along with three 24-inch monitors to train the tasks of map interpretation and terrain association. This desktop system was fielded at Helicopter Antisubmarine Squadron 10 (HS-10) for experimentation.

Results of this experiment indicate that student pilots who received VE training performed the navigation task better in the helicopter than students who received only conventional training.. Also, an IT-21 Wintel based computer is capable of rendering a graphically intensive multi-monitor application at frame rates suitable for training.

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AN INTERACTIVE VIRTUAL ENVIRONMENT FOR TRAINING MAP-READING SKILL IN HELICOPTER PILOTS

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MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

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ABSTRACT

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I. INTRODUCTION

A. PROBLEM STATEMENT

Navigation is one of the many important tasks pilots must accomplish while executing missions. While navigation can consist of flying at high altitudes and using radio navigational aids such as VHF Omnidirectional Radio (VOR) and Tactical Air Navigation (TACAN) beacons, this is unlikely in tactical scenarios because at low altitudes these signals are difficult to aquire. High altitude flight profiles are reserved for routes over friendly territory where there is little or no enemy threat. Radio navigational aids (navaids) have limited range and are "line of sight" beacons, meaning that one's altitude must be high enough to receive the navaid's signal. This is not a problem during the transit phase of missions where there is no enemy threat because low altitude flight profiles are not required. However, when the enemy threat is high, low altitude flight profiles are utilized and standard electronic navaids can rarely be employed.

Low altitude profiles are advantageous for several reasons. First, by flying low to the ground, the helicopter crew can use the terrain features to hide the aircraft from the enemy. This is called terrain masking. The concept of terrain masking can be described as simply putting something (in this case, the terrain) between the aircraft and the enemy. By using the cover of trees, the depth of a canyon, or the height of a mountain, the helicopter crew can make it much more difficult for an enemy to locate and threaten the aircraft. By staying low and using terrain masking, the aircraft is less likely to be detected because the helicopter's radar signal is lost in the echoes returned by the ground. Also, the helicopter's noise signature is reduced because the surrounding terrain can

absorb the sound produced by the rotor blades and engines. Because of these advantages, low altitude flight is an essential part of any helicopter tactical mission.

However, all the advantages of terrain masking inherently produce some disadvantages. Flying at low altitudes is extremely dangerous and stressful. The aircrew must be highly trained in the use of terrain flight (TERF) techniques. TERF is much different than high altitude flying because the aircraft is much closer to the ground. Helicopter TERF profiles are exemplified by airspeeds between 90 and 120 knots and altitudes between 50 and 200 feet. During turns in TERF profiles, the fuselage of the aircraft is no longer the lowest point to the ground. The rotor arc becomes the lowest point and it may only be several feet from trees or the ground itself. This makes flying the aircraft challenging and pilot error in TERF profiles can be fatal.

Another disadvantage is that navigation at low altitudes becomes extremely difficult vice high altitude navigation. As the aircraft's altitude decreases, the number of terrain features that an aircrew can use for visual navigation decreases as well. Aircrews can only see terrain features in their immediate vicinity. With the limited number of terrain features comes a limited number of navigational references increasing the possibility of becoming disoriented and lost. If an aircrew becomes disoriented in hostile territory the results can be disastrous. Combine this with the fact that electronic navaids cannot be reliably used and a strong argument can be made for capable and effective training systems for map interpretation and terrain association.

B. MOTIVATION

The current methods for training Naval Aviators the task of map interpretation and terrain association are barely acceptable. In fact, most practical training happens in

the air. Due to the high cost of flight time, this is an unacceptable situation. The training aids designed for this purpose are antiquated and merely scratch the surface for providing the tools necessary to successfully navigate from 1:50,000 contour maps. Using technological advances in computer graphics subsystems and virtual environment technology, a computer system can better address these training requirements. A computer-based trainer (CBT) allows a student to interact with the system instead of passively watching a video tape. CBT's also provide immediate feedback so students can gauge their progress. Lastly, CBT's provide unlimited repetitive training and practice. LCDR Joseph Sullivan created one such system at the Naval Postgraduate School. His system, called Map Interpretation Terrain Association Virtual Environment System (MITAVES) provided evidence to suggest that student pilots that used MITAVES actually demonstrated increased navigational performance in the air during training flights (Sullivan, 1998). However, MITAVES is not IT-21 compliant and the hardware for MITAVES is out of date. The next step towards development of such a system is a reimplementation on consumer of the shelf (COTS) hardware and future evaluation. The goal of this research is to demonstrate that an IT-21 hardware compliant system can be created with state of the art hardware. This new implementation, named MITAVES II, will then be tested to verify if this new system can indeed increase the navigational performance of student helicopter pilots.

C. RESEARCH QUESTIONS

There are several questions that this research hopes to answer. First, can a system that is compliant with the Information for the 21st Century (IT-21) concept, be built that can handle the graphics intensive tasks required of a computer-based flight simulator?

Usually this type of task is reserved for high end UNIX-based systems that specialize in rendering graphics intensive applications. This research hopes to show that a Windows NT-based system is up to par with the UNIX based systems given the demands of this training task.

Secondly, can a Windows NT-based system use higher fidelity data and render a higher fidelity model than the previous system? The data used in the first MITAVES system was relatively low resolution. So, if low-resolution data can be used with positive results, can the same results be achieved with higher resolution data and models and can this improvement be quantified?

Lastly, can the IT-21 system using higher resolution models be shown to train the tasks of map interpretation and terrain association? One goal of this research is to bring relatively inexpensive hardware and software together in order to create a trainer to teach map reading skills. Once the trainer is created, can it be shown to effectively teach map-reading skills to student pilots? If this can be proven, then the training flights now reserved to teach map reading skills in the air can shift their focus from ***training*** map-reading to ***verifying*** map reading skills. Wasted time spent training this task in the air can then be concentrated on teaching advanced navigation techniques and how to actually perform the task of terrain flying. Another goal then, is to take the piloting skills that can be taught on the ground and keep them there, thus better utilizing expensive and limited flight time for teaching the skills that pilots can only learn in the cockpit.

D. ORGANIZATION OF THESIS

This thesis is organized into the following chapters:

1. Chapter I: Introduction. This chapter includes an introduction to the problem, motivation, and outline for this thesis.

2. Chapter II: Background. This chapter contains pertinent background information including a summary of Sullivan's work, a description of current training methods, and an explanation of the concept of Information Technology for the 21st Century (IT-21).

3. Chapter III: Specifications. This chapter provides a specification for a computer based navigational training system.

4. Chapter IV: Implementation of the Specifications. This chapter describes the implementation of the MITAVES II system according to the specifications outlined in the previous chapter.

5. Chapter V: Evaluation. This chapter describes the experiment that evaluates the MITAVES II system and how the data was recorded and analyzed.

6. Chapter VI: Hardware Experiment. This chapter reports results from an experiment with Windows 98, Windows NT, and consumer level graphics cards running the MITAVES II application.

7. Chapter VII: Conclusions. This chapter contains the conclusions reached from the testing process.

8. Chapter VIII: Future Work. This chapter describes the research and implementation ideas that the author was unable to perform due to time or technology constraints.

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II. BACKGROUND

A. TASK ANALYSIS OF MAP INTERPRETATION AND TERRAIN ASSOCIATION

When a squadron receives a tactical mission, an optimal route is planned from the landing zone to the squadron's base. The route is based on the terrain and the current enemy threat obtained from intelligence sources. A good route uses the terrain to mask aircraft from the enemy. If there are known enemy threats in the area, then threat rings are also depicted on the map. Threat rings represent the threat's range and location. A circle is drawn with the threat's position as the center and the radius of the circle represents the threat's range. Flying through the threat rings should be avoided unless there is an obstacle, such as high terrain, between the threat's position and the aircraft's route of flight. Routes are also chosen so that easily identifiable landmarks can guide the aircrew. These landmarks should be prominent terrain features instead of man-made features so that the route would not be compromised if the man made features were destroyed or missing. Because it is undesirable to fly through enemy territory to the objective area and then return to the base using the same route, both ingress and egress routes are planned. Since the enemy was alerted to the presence of the aircraft from the first fly over, it would be dangerous to fly over again using the same route. Also, the secondary route can be used to accomplish the mission if the enemy threat has changed from the time the mission route was planned.

Once the route is chosen, it is time to rehearse. Rehearsal is accomplished by visualizing the terrain along the route. Aircrews visualize the terrain through map interpretation. The map is studied as much as possible before the flight so that the aircrew is completely familiar with the information represented on the map. If time

permits, “what if” scenarios are created. For example, a member of the aircrew may say, “What if we started taking fire from on top of this ridge, what would we do?” Possible reactions to this threat are then discussed. Natural terrain features are utilized to cue the aircrew that they have missed or passed a checkpoint. These features are called *limiting features* and they help the aircrew stay on the route. 1:250,000 scale maps are used for a majority of the transit between the base and the landing zone. This is because these maps are manageable and easy to handle in the cockpit. They offer a good mix between contour lines and high-level map symbology. 1:50,000 scale contour maps are only used when the aircraft approaches five nautical miles of the landing zone. These maps offer a higher level of detail and are good for planning landing zones. These maps are used to pinpoint landing locations, to identify terrain features for masking, and for identifying obstacles and flight hazards. Because two different maps are utilized, a map changeover point is briefed so every aircrew on the mission is reading the same map at the same time. The change over point is a checkpoint that is depicted and easily identified on both maps.

Flying with two different scales of maps presents a challenge to the pilot. When using a high scale map, the aircraft moves much slower over the paper than when a low scale map is used. For example, one inch on a 1:250,000 scale map is approximately 6500 meters while one inch on a 1:50,000 scale map is approximately 1300 meters. When changing between maps, the pilot must recognize this fact and adjust accordingly. This concept is often a major learning point for novice pilots and needs to be thoroughly taught in the training syllabus.

During the execution of the mission, the aircrew is busy flying the aircraft and looking for enemy threats. At the same time, the aircrew is performing the tasks of map

interpretation and terrain association as they navigate from checkpoint to checkpoint. Terrain association is the act of correlating the mental model to its corresponding real world terrain. The tasks of flying the aircraft and terrain association are split between the two pilots in the helicopter. One pilot is in charge of safely flying the helicopter. The other pilot is responsible for navigation. The navigation skills of map interpretation and terrain association must be taught and are not intuitive nor natural. The map interpretation and terrain association tasks are introduced to Student Naval Aviators (SNA) with the Map Interpretation and Terrain Association Course (MITAC).

B. CURRENT TRAINING WITH MITAC VIDEOS

The current introduction to map interpretation and terrain association that takes place in flight school for helicopter student Naval Aviators is called the Map Interpretation Terrain Association Course. This course is designed for students who have completed their primary training in the TH-57 Bell Jet Ranger and are now in the intermediate stage of their training. The students are completely familiar with how to fly the aircraft and are now beginning to learn about helicopter tactics. The first stage of this training is to familiarize the student with how to read a 1:50,000 contour map. The course is VHS based. Students watch a videotape and an instructor supplements the video by answering student questions. The video series is divided into two parts. The first part deals with how the contour lines on the map represent the terrain features on the earth. Various examples of contour lines representative of major terrain features, such as mountains and valleys, are shown and correlated to actual pictures of the terrain. Students are also instructed on the standard terminology used to describe terrain. Lastly, contour map symbology is introduced.

Because it presents material that needs to be memorized, this portion of the MITAC course is an excellent introduction to map interpretation. Wickens (1992) describes this is as declarative knowledge and suggests that this kind of knowledge is best learned through study and rehearsal. By describing and elaborating on material that needs to be memorized, this portion of the video results in a solid introduction to the terminology, map symbols and map interpretation specifics.

The second part of the course instructs the student on how different environments, such as desert or mountainous terrain, are represented on contour maps. More importantly, this part of the course is an introduction on *how* to associate the terrain to the map. This technique is called terrain association. The first part of this series is a period of map study. Students are familiarized with how the terrain from a specific area is represented on the map. Then the flight period begins by showing a helicopter moving approximately twice its normal speed over the terrain. While watching the videos, the student uses a laminated contour map and a grease pencil. It is the students' task to interpret what they see as the helicopter's flight path over the ground and trace the path onto the laminated map. The last period is a flight debrief that re-flys the terrain and stops at key places to show students the cues that they should have been looking for as the flight progressed.

This portion of the MITAC course is ineffective for several reasons. First, while students' heads are down looking at the map, they miss a lot of information that is up on the video screen because the aircraft is moving so fast. Also, since a single video screen is used, the students' field of view is limited to what is directly in front of the helicopter. Because of this fixed point of view, the student has no choice but to look forward even if

the student wants to look to the side for other navigational cues (which is considered good technique). Lastly, MITAC videos are not interactive. There is no ability to track students' progress so they never know if they are on the right course or if a mistake has been made. The system does not allow a student to go back and correct a mistake.

Due to these shortcomings of MITAC videos, students often make mistakes very early in the videotaped flight. Because students usually make mistakes during the first minute of the tape and the helicopter does not stop until the tape is over, a five-minute training evolution quickly becomes useless and counterproductive. These mistakes compound upon each other and the students' final flight path on the map looks nothing like the actual path of the helicopter. This may cause students to lose confidence in themselves when it comes to performing these tasks in the helicopter. Because students may feel uncomfortable performing these tasks during the training flight, their apprehension may be a barrier to learning.

This portion of MITAC is trying to teach students how to perform the task of map interpretation and terrain association. These tasks are best described as procedural knowledge tasks that Wickens (1992) defines as performance of an action. Wickens (1992) suggests that procedural knowledge is best learned through performance and practice. The second half of the MITAC training violates several of the points that Wickens (1992) makes with regards to training. Wickens (1992) suggests that it is crucial that students not be allowed to make mistakes early in their training. Preventing errors early on will reinforce only the proper habit patterns related to the task. Allowing a student to make a significant amount of mistakes while learning a task can lead to

negative training. MITAC videos allow students to make errors without any type of correction thereby limiting its value as a training tool.

The MITAC training does not increase in difficulty as students improve. Adaptive training as described by Wickens (1992), does not overwhelm students early in their training, but instead gradually becomes more challenging as the student's ability to perform the task increases. MITAC videos maintain the same level of difficulty and are not adaptive.

Wickens (1992) suggests that knowledge of results can be beneficial to students. Feedback, either positive or negative, can encourage students doing the task correctly and can help students to catch mistakes as they are made. MITAC videos provide no feedback while the route-tracing task is performed, so students are kept in the dark until the task is over.

C. SUMMARY OF SULLIVAN'S RESEARCH

The Naval Postgraduate School has been experimenting with virtual environments and a human's ability to navigate within them. Experiments have explored both buildings and open terrain as virtual environments. Studies have included: Major William Banker's Virtual Environments and Wayfinding in the Natural Environment (Darken and Banker, 1997), Captain Simon Goerger's Spatial Knowledge Acquisition and Transfer from Virtual to Natural Environments for Dismounted Land Navigation (Goerger, 1998), and LtJG Helsin Cevik's Map Usage in Virtual Environments (Cevik, 1998). One open terrain experiment by LCDR Joseph Sullivan, has identified helicopter pilots as the principle subjects (Sullivan, 1998). In this work, a desktop computer system was developed to teach helicopter pilots how to navigate using 1:50,000 contour maps.

The computer was an Indigo2 graphics workstation from Silicon Graphics Inc. (SGI). The system was composed of a single R4400 200 MHz CPU, 128 Megabytes of RAM, a High Impact graphics board with 1 megabyte of texture memory, and an IMPACT Channel Option Board. The IMPACT board allowed for the use of up to four monitors. Three 19-inch monitors were set up in a semi-circular configuration, which provided 95 degrees field of view. A Flybox from BG Systems, Inc. was used as the control device and consisted of a control stick similar to that in an aircraft. The stick had a trigger button on the front, and the stick itself was able to rotate about its axis to provide for yaw control if necessary. There are 10 buttons and two additional levers on the base of the Flybox. One lever was used for speed control and the buttons were not used at all.

The software for the simulation was developed using the Performer application-programming interface (API) from SGI. A simple form of terrain following was created so the flight interface did not let the helicopter crash into the ground. An altitude, bearing, and speed was set and the virtual helicopter flew itself. This was necessary because the student was both flying and navigating at the same time. For both of these tasks to be accomplished simultaneously, the motion model and flight interface needed to be as simple as possible. Figure 1 shows how the simulation was divided into three 640 x 480 resolution monitors with a seven degree gap between the monitors to account for the monitor's plastic casing.

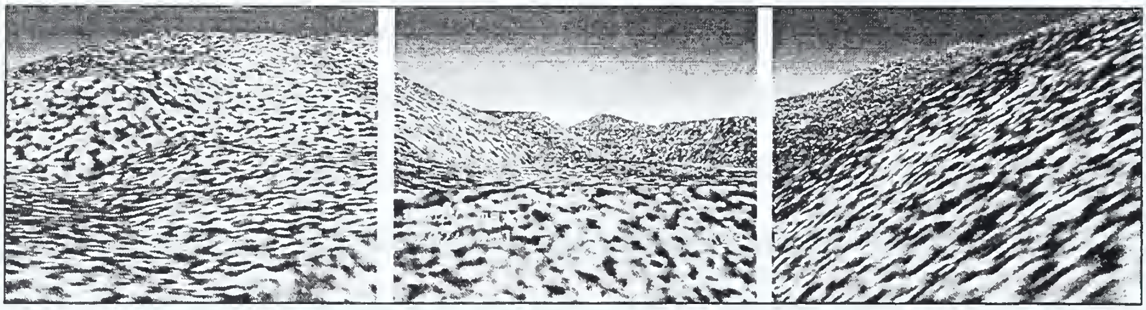

Figure 1. A Three-Screen View with Gaps Between Monitors.

A heads-up display, shown in Figure 2, was used to give the student important information relevant to the flight. This information included numbers for the barometric altimeter, radar altimeter, heading, and airspeed.

Figure 2. The MITAVES Heads Up Display.

Mechanisms for increasing a student's situational awareness in the simulation were included. These mechanisms were developed with the intention of making it easier to teach a student the art of map interpretation.

One mechanism was the ability to control an exocentric, or external, viewpoint within the virtual environment. The exocentric viewpoint can be thought of as a controllable camera that allows the user to see gain an advantageous viewpoint from outside of the helicopter. Previous studies suggest that an exocentric view is useful for information about a large-scale space. (Koh, 1997; Elvins 1998) "This view can be useful

for navigation because it shows the local context around the viewpoint without losing perspective"(Sullivan, Darken, & McLean, 1998). Sullivan decided to integrate the egocentric and exocentric viewpoints. To accomplish this, the student can detach the egocentric camera and move up and away into an exocentric viewpoint. This facilitates a smooth transition from the egocentric to the exocentric viewpoint and keeps the user oriented. Also, this method minimizes the potentially disorienting effects from sudden teleportation to a different location. When a student pulls the trigger on the Flybox stick, the camera was detached from the egocentric viewpoint and gradually moved up a ten-degree slope away from the helicopter. Once away from the helicopter, the viewpoint could be moved in a circle about the helicopter at a radius determined by the distance between the viewpoint and the origin. A circle was used to keep the student continuously oriented towards the helicopter located at the center. When the trigger was released, the viewpoint was rotated along the path from the final exocentric position and zoomed back to the helicopter. By retracing the path, the user presumably will be kept oriented and loss of situational awareness will be minimized.

Another mechanism for teaching map interpretation is the "You Are Here" (YAH) map. This map was developed with the intention that students would use it anytime they were disoriented or lost. Presumably, the less time a student spent lost in the virtual environment, the more time the student would learn how to interpret the map to the corresponding virtual terrain. When the space bar was pressed, a window was displayed containing a digital representation of the paper map used for navigation. When the YAH map was displayed, the motion of the helicopter was stopped so the student could not simply call up the map and spend time following the route line on the map.

The ability to zoom in and out of the virtual map was given to the student through the use of the second lever on the Flybox. By pulling the lever back, the student could see the entire route, and by pushing the lever forward, the student could zoom in and see the fine detail of the map. A symbol to represent the student's position on the map is always centered on the map's window. The top of the map was always relative to the direction the student is flying instead of a constant "north-up" view. This was because previous studies suggest that track-up maps are best for egocentric tasks such as navigation. (Aretz, 1992; Levine, 1982; Cevik, 1998) Route information was displayed as a black line and the student's track was represented as a red line. With this information, students can instantly tell whether or not they were on the route. If students were off the route, they would know by how much and the direction they would need to take to get themselves back onto the route. Students would also be able to return to the exact position in which a mistake was made and analyze their thought process so a similar mistake would not be made in the future.

The terrain database was virtual Camp Pendleton, California. This area was used because it was where the candidate students would be conducting their terrain flight training. Digital Elevation Terrain Data (DTED) level 1 and geo-rectified multi-spectral satellite imagery was used to create the terrain database. DTED level 1 is 100-meter resolution and the imagery is 30-meter resolution and rendered in color. Due to the low resolution of the texture, the terrain was rendered as large colored blotches at low altitudes in the database. This lack of resolution provides little contrast between terrain features and also makes determining relative ground speed very difficult. These

limitations forced the use of a detail texture to be added to the imagery in order to make the terrain easier to interpret.

Sullivan's experiment was conducted with students from fleet replacement squadron HS –10 at North Island. An experimental group received an hour of instruction on the trainer while the control group did not receive any additional training. Then both groups were evaluated during their first terrain interpretation and navigation flight in the helicopter. In addition to the syllabus-required comments from the instructor, instructors were asked to answer a few additional questions concerning the student's navigational performance and the student's general situational awareness. Sullivan concluded that students were able to correlate the contour map to the terrain in the virtual environment. Also, the interface and the feedback given by the system were found to be effective thus increasing the student's ability to resolve an egocentric view with a contour map representation.

Sullivan's work is not without its weaknesses. First, MITAVES uses specialized hardware and is not IT-21 compliant. This makes maintaining and administrating MITAVES difficult. Users and administrators must be familiar with the UNIX operating system in order to utilize MITAVES. All the hardware is SGI proprietary hardware. This means that if a monitor malfunctions, a new replacement monitor must be obtained from SGI. It would not be possible to use PC monitors that are readily available in the squadron because they are not compatible with the SGI hardware. This limitation, in and of itself, could discourage wide-scale deployment of the system in the fleet.

The evaluation of the MITAVES system at HS-10 was only cursory. Although more students were anticipated to use the system, only a handful were actually evaluated.

A larger control and experiment group needs to be utilized in order to accomplish a more meaningful analysis. The analysis showed that the MITAVES system worked but it could not identify why it was successful.

Some of MITAVES' interface components were unverified. For example, a generic computer representation of a contour map was used for training map interpretation. Although Sullivan's reasons for using this map were justified, utilizing this map was a departure from the standard maps that pilots are accustomed to using in the aircraft. Optimizing training transfer requires further analysis of interface components.

The fidelity of the terrain model in MITAVES is relatively low. MITAVES used DTED level one. This resolution of DTED offers only the coarsest of data for elevation relief. Higher resolution elevation data is available and can provide a higher fidelity model. Higher resolution satellite imagery is also available and would add to the fidelity of the model as well. If it is desirable to use standard NIMA maps as would be used operationally, then better resolution is needed so that maps and virtual terrain will match.

D. INFORMATION TECHNOLOGY FOR THE 21ST CENTURY

The Quadrennial Defense Review of May 1997 called for significant manpower reductions (QDR, 1997). As shown in Table 1, this forces the Department of Defense armed services to accomplish their mission with fewer personnel in uniform.

DEFENSE MANPOWER				
	Programmed Force			
	FY 1989	FY 1997	FY 2003	QDR
Active*	2,130,000	1,450,000	1,420,000	1,360,000
Reserve	1,170,000	900,000	890,000	835,000
Civilian*	1,110,000	800,000	720,000	640,000

Table 1. Defense Manpower Force Projections.

If used effectively, computers allow a smaller force to accomplish a greater number of tasks with greater efficiency. As PC-based technology finds its way into every government agency and workspace, competition between software and hardware venders have created a bevy of standards and platforms in which to choose to accomplish an agency's mission. Different agencies choose different standards. For example, in 1995 the United States Marine Corps made a decision to use Lotus SmartSuite as its primary office automation software while the United States Navy chose to use Microsoft Office 95. While each office software suite was equally capable and helped each service accomplish its mission, the suites did not have compatible formats, which created problems in data transfer and sharing. This created a barrier to effective communications between the services. As smaller budgets require the Department of Defense to work in a joint environment, communications between the service components of the DoD is vital for mission success. The first step toward the necessary goal of common PC-based platforms is a common set of standards for computer hardware and software. It is on this premise that the concept of Information Technology for the 21st Century (IT-21) is born.

Joint Vision 2010 (JV2010) is the roadmap for the direction of the United States armed forces (JV2010, 1996). JV2010 (1996) describes a highly intelligent force of warriors that know how to use the United States' leading position in technology to their advantage for accomplishing their mission. JV2010 (1996) says technology is the key to full spectrum battlefield dominance and IT-21 is the Department of the Navy's answer to achieving information superiority.

IT-21 was promulgated by standard Navy message in March 1997 (IT-21, 1997). IT-21 (1997) describes the direction and implementation of the IT-21 concept. IT-21

(1997) directs that all Department of the Navy activities will use PC solutions based on the Windows/Intel platform. Microsoft Windows NT 4.0 will be the standard operating system and software such as Microsoft Office 97 and Microsoft Exchange 5.0 will be the IT-21 standard for office automation. It also directs a minimum standard for future purchases of PC hardware. The minimum speed of an Intel Pentium processor is 200 MHz, the minimum memory is 64 megabytes, and a 100 Mbps network interface card is required for all PC desktop systems.

Although simulators and training systems are not required to conform to IT-21 standards, it would be beneficial if they did. If all systems ran on a common platform with common hardware, when a piece of hardware failed, it could be replaced from a central supply of computer parts. Also, if a common platform is utilized, an administrator of one system could become an administrator of all systems with little additional training.

III. SYSTEM SPECIFICATIONS

An analysis of the tasks of map interpretation and terrain association was conducted (See Chapter II.A). Based on this analysis, it was decided that a computer-based trainer is the best choice for teaching these tasks. This stems from Wickens' (1992) theory training procedural knowledge. Helicopter navigation is the performance of the tasks of map interpretation and terrain association. These tasks are procedural knowledge tasks as they are the performance of actions. Because the training of procedural knowledge is best acquired through practice and performing, a simulation of these navigation tasks is assumed to be the best choice for training them. In other words, actually doing the task is the best way to learn it therefore a simulation would be ideal for teaching helicopter navigation. Using a computer-based model, a simulation can be developed that takes advantage of the strengths only a virtual environment (VE) can offer. For example, there is no limit to the number of viewpoints available in a VE. The viewpoint or camera can be moved to any point in the simulation to provide the best possible vantage-point for the task at hand. Also, VE's can be constructed so that there are no physical constraints in the system. This means the user can move in any direction, thus breaking the conventional laws of physics in order to gain the most advantageous position for the learning process. VE's also overcome the limitations of the MITAC videos by providing a wide field of view and an interactive learning environment.

Based on the analysis in Chapter II.A and input from instructor pilots at HS-10, the following general specifications, requirements, and constraints are suggestions for a computer based navigation trainer. These requirements can be divided into the following categories: system, interface, model, method, training aid, and testing and evaluation.

A. SYSTEM REQUIREMENTS

System requirements are those that describe the hardware and its general characteristics. In general, these specifications deal with generic constraints of any military training system, not specifically MITAC.

1. The System Must be Unclassified at its Lowest Level

At its lowest security level, the system must be unclassified. The requirement that the system be unclassified stems from the fact that it must be able to reach the broadest audience. Student aviators may not have a security clearance above SECRET and the training device must not be denied to them because they do not have the proper clearance. Student aviators from foreign countries attend flight school in Pensacola, Florida, and the system must not be denied to them as well. Although most squadron spaces have a safe to store classified materials, including hard drives that contain classified material, it is inconvenient for users and administrators to handle classified material. The extra steps that need to be taken in order to use a classified system, such as going to the safe to check out the hard drive for the system, may be enough to stop a student from using the system in the first place. There must not be any barriers in place that may hinder a students' access to the system. However, since aviators who are not in a training status may also use the system, the possibility of making the system classified must not be ruled out. The only requirement then, is that the system must be able to be used at an unclassified level.

2. The System Must Comply with IT-21 Standards

The system must comply with IT-21 standards. As described in Section II.D, the message that generated the IT-21 standards mandates that all future computer systems implemented by the Department of the Navy comply with the minimum IT-21 standards.

This is to help insure that all hardware and software are compatible with one another and that they are maintainable. Hardware that complies with the IT-21 standards would have parts that are modularized thus ensuring interchangeability. The system administration of computer hardware that runs the same operating system, such as Windows NT, is also advantageous since a common platform is easier to manage.

3. The System Must be Deployable

As units and squadrons deploy to other areas or aboard ships, they need to take their gear and equipment with them. Often, the equipment is placed into stackable wooden boxes and loaded into transport aircraft for shipment. Computers and monitors are usually put back into their original boxes or wrapped in bubble wrap. Most standard medium to full size computer tower and desktop cases would be considered to be deployable. Units also deploy with standard 17-inch monitors therefore they would have to be considered deployable as well. A deployable system would need to have a small footprint in order to fit into already cramped quarters on the ship. In addition, a deployable system would have to be rugged in order to withstand the jolts of being moved from shore to ship bases.

4. The System Should Not Need A System Administrator for General Use

A system administrator should not be required to run or operate the system for the student. The system must be totally self-contained, resulting in a "walk-up-and-use" system with little to no required familiarization. The reasons for this are obvious. The user should not be required to have anything but minimal Windows operating system user experience. A system administrator should not have to create an account for each user

who wants to use the system. Once the system is loaded onto the computer, there should be no other maintenance required in order for the user to operate the system.

5. The System Must Use an Open Systems Structure

The system must be built with options to evolve into a mission planning and rehearsal tool. Since terrain and maps are elements that are used in navigation, mission planning, and mission rehearsal, it is a natural progression for a navigation trainer to evolve into a mission rehearsal tool. Also, closing the system so these options can not be realized only jeopardizes the system's ability to become multifunctional. As budgets become tighter, more functionality is expected from smaller and less expensive systems. If the system is built using well-known standards and data formats, it would not be difficult to develop a navigation tool into the utility of a mission rehearsal tool.

6. The System Should be Based in Real-Time

The computer-based system must be a real-time based simulation. In other words, the trainer must correctly render the virtual environment at the correct headings and speeds. If the airspeed indicator states that the aircraft is flying at 120 knots, then the system must render the simulation at 120 knots. Heading must be correct as well. A heading of 090 must be pointing to the east in the real time system. It is not implied here that the computer operating system must be capable of processing the simulation in real-time, only that care is taken to ensure that the simulation functions with the proper time/space consistency.

It is important that the simulation take place at the same speeds that they happen in the real world because the system will be teaching a real world interactive task. In teaching procedural knowledge, rehearsal is key. Therefore the goal for the real-time system is to practice the task like the task will be performed in the real world. MITAC

videos are not based in real-time because the helicopter is moving about twice as fast as normal.

B. INTERFACE REQUIRMENTS

Interface requirements deal with how the user interacts with the system and the controls. These requirements are very important because if a system is not usable, students may not see any benefits from using the system. A "perfect" VE model could be developed, but if it had a poor interface it would not be used. The interaction between the user and the system must be taken into account during every step of the development process. This is to ensure that the user will benefit from the training that the system can potentially offer.

1. The Trainer Must be Easy to Use

There must be little or no training required to use the system. Students are already overburdened with new information to absorb. New flight procedures, emergency procedures, and tactics are a few examples of the kinds of knowledge students are expected to understand. Students may not have time to learn how to use another training system. If students are faced with making the choice of studying for the next flight or studying how to use a training system, they may not choose to figure out how to use the trainer. Students must intuitively know how to effectively use the trainer the first time they sit down to use it. If the system were too difficult to figure out, presumably, this information would be shared among the students, resulting in low utilization of the system.

After completing a training session on the system, students should gain confidence in their navigational and map reading abilities. An increase in confidence would allow the student to make more aggressive decisions while navigating in the

helicopter and permit the student to push the training envelope. Students who are confident in their navigational abilities may make bolder decisions in the training environment. If they do, then they can test themselves and their abilities to see what skills they need to improve. They may find out that they do not need to improve their skills at all, but if they do not have the confidence to push themselves early in the training, then this opportunity for improvement could be lost.

2. The Trainer Must be Easy to Control

The motion model must be very straight forward in order to allow a single user to fly and navigate at the same time. A two-person crew normally performs the tasks of flying and navigating. The flying pilot is responsible for the safety of the helicopter. It is the flying pilots' job to keep their head out of the cockpit and safely maneuver the helicopter. The flying pilots' main goal is terrain and obstacle avoidance. The non-flying pilots' job is to navigate. The non-flying pilot is responsible for map interpretation and terrain association. The non-flying pilot gives the flying pilot commands such as "turn left" and "stop turn" in order to navigate to the destination.

By the above description of the real world tasks related to flying and navigating in the helicopter, a system may force a single user to perform both tasks. To this end, the motion model must be easy enough to control so that a single user can maneuver the virtual aircraft and perform map interpretation at the same time. The virtual aircraft must not be allowed to slip out of control while the student's attention is focused on map interpretation and not on flying. In addition, the motion model must not allow a user to move the aircraft so fast that disorientation may occur. This might happen if the turn rate or rate of climb is too fast. In this case, students would not be able to turn to a specified

heading without overshooting. Also, if the motion model were dampened to the other extreme then rate of turn would be too slow. This would not allow the user to make turns with a small turn radius and control of the aircraft would be very frustrating. For example, when students try to turn to a specified location with a slow turn rate, their radius of turn would be so large that they would fly a wide circular path around their intended course.

3. The Trainer Must Have a Wide Field of View

Helicopter pilots inherently use their peripheral vision to navigate. As stated in (CNO, 1992, p. 13-4): "For terrain navigation, use is made of both the central and peripheral visual fields, but the peripheral is the decisive field." As helicopters fly at low altitudes, there is less information available. Because of this, helicopter pilots use their peripheral view in the helicopter in order to gain as much information as possible about the surrounding terrain. If a narrow field of view is used for training, negative training may occur by teaching students to only look to their front for navigational cues. It is important for students to break the habit of "tunnel vision," and instead "keep their head on a swivel" or look to the sides for important navigational information.

The field of view of the computer-based system should not be limited to what can be represented by a single monitor. The technology exists to configure a computer's graphics subsystem to output to multiple monitors. These monitors should be linked in such a way that a much wider field of view can be obtained. The field of view should approach what is typically in an aircraft. For example, the field of view in an SH-60 helicopter is approximately 160 degrees so the goal field of view for the trainer should be as close to 160 as possible.

A system with a wide field of view will increase the use of peripheral cues better than a system with a lower field of view. To illustrate this, two aircraft are utilized. Aircraft 1 has a field of view of 30 degrees while Aircraft 2 has a field of view of 90 degrees. If both aircraft are flying at 90 knots and see a feature 0.5 NM from their intended track, then the aircraft with the wider field of view will have the terrain feature in its viewpoint for 54 more seconds than the other aircraft (Sullivan, 1998, p.16). This time can be used to better orient the pilot, thus increasing situational awareness.

4. Flight Information that Must be Available

At a minimum, the following information must be available to the student: heading, barometric altimeter, radar altimeter, and airspeed. This information is always available to pilots and represents the minimum information that pilots need to orient themselves and their aircraft. Heading is needed to orient the pilot relative to true north. The barometric altimeter is required to determine the height of surrounding terrain. The radar altimeter gives height above the ground to prevent the aircraft from crashing into the terrain. The airspeed is required to gauge ground speed and for timing. Pilots increase their situational awareness and keep themselves from becoming disoriented by utilizing all of this essential flight information.

C. METHOD REQUIREMENTS

The method requirements describe the overall usage of the system. They describe what the minimum tasks are in order to train the student properly and describe how the system should be utilized.

1. The System Must Train the Tasks of Map Interpretation and Terrain Association with 1:50,000 Scale Contour Maps

Above all else, the computer-based system must train the tasks of map interpretation and terrain association using 1:50,000 scale contour maps because this is the overriding motivation for this research. Tools must be available to the user of the system that increase a student's situational awareness, spatial orientation, and navigational ability. By increasing these factors it is assumed that a student's ability to navigate in the helicopter will increase. These tools must train students to translate the contour lines from standard National Imagery and Mapping Agency (NIMA) maps into three-dimensional mental models. Students must then associate the mental model to the actual terrain. If the student's mental model is incorrect, the system must show students that an error was committed within a short period of time and allow the students to correct themselves.

2. The System Must Provide User Feedback

To minimize the effects of negative training transfer it is important that a student's mistakes be identified early. If students are allowed to continue map interpretation while they are lost or disoriented, negative training transfer may occur. If students feel that they are on course when they are not, then unprompted cues for students should be provided to stop the student before they wander too far off course. These cues must not come so early that students can not catch their own mistakes, however the cues must not come so late that students can not effectively correct themselves.

When students ask the system for help, feedback must be supplied that positively identifies a student's position relative to the track they are required to follow. After

receiving this information, students can then formulate a plan for getting back on course if they were previously disoriented.

3. The System Must Record a History of the Training Event

A history of the training event must be recorded. This is necessary for later analysis of the flight. Student progress can be tracked and an analysis of the student's performance can be completed. The analysis can include student trends so the same frequent mistakes can be detected and corrected. If a history is kept, then the student's track can be displayed when they ask for it in order to compare it to the route they are supposed to follow. The history is also useful for user feedback. By reviewing the path that they flew, students can see where mistakes were made or confirm that they were on the route.

D. TERRAIN MODEL REQUIRMENTS

1. A High Fidelity Virtual Environment Must be Used

The virtual environment used in the trainer must have a level of detail consistent with the task of terrain association. In other words, the fidelity of the terrain model must be high enough to facilitate the task of reconciling the student's mental model to it and to the map as well. There must be enough polygons present in the terrain model to adequately render terrain that can be visualized in a 1:50,000-scale contour map. There is a possibility of negative training transfer if terrain features that can be visualized from the map are not rendered in the terrain model. The same holds true if there are artifacts generated in the terrain model that are not depicted on the map.

In addition to a high polygon count, a high-resolution texture must be utilized. When models are rendered at low altitude viewpoints, a texture's pixels become very

large. The enlarged pixels create a patchwork of color that does not represent the actual depiction of the earth. One enlarged pixel may cover a large area in the VE resulting in a pattern of blotchy color over the terrain. This has two negative effects.

First, the resulting patches do not provide adequate contrast for delineating terrain features. A change in elevation is not apparent until the viewpoint is very close to the terrain feature. This makes terrain association difficult, as terrain features may not be identified early enough to make use of the information.

Second, the large blotches do not do an adequate job of providing a sense of speed during the simulation. During forward motion at low altitude viewpoints, users would see a small number of large patches coming towards them. Users perceive this as moving slowly, even though the simulation is properly rendering high velocities. Users perceive high velocities by seeing a large number of objects rushing by during forward motion. If a high enough resolution texture were used as the terrain skin, the pixels would not become so large and spread out, thereby providing the objects for proper velocity perception.

E. TESTING AND EVALUATION REQUIRMENTS

1. The System Must be Proven To Work

Evidence must exist that proves the system can actually train the tasks of map interpretation and terrain association. The Department of the Navy can no longer blindly purchase and develop training technologies simply because they look good. Experiments must be conducted that prove the system can perform the tasks it was designed to accomplish. Without this proof, the possibility of negative training transfer can not be discounted.

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IV. IMPLEMENTATION OF THE SPECIFICATIONS

This chapter will address each specification and explain how they are implemented in the MITAVES II system. Where appropriate, detailed explanations will be provided which discuss how certain implementations were accomplished.

A. SYSTEM REQUIRMENTS

1. The System Must be Unclassified at its Lowest Level

a. Hardware

The hardware used to implement the MITAVES II system is all unclassified and was built by Intergraph Corporation. MITAVES II was originally implemented on an Intergraph TDZ 2000 GL2, PII 400, 128 Megabytes of RAM, and a single Realizm II VX-113 with a 21-inch monitor. The VX-113 has 16 Megabytes of texture memory and no geometry acceleration. The single screen implementation was merely a stepping stone to a multiple screen configuration. Migration to a three-screen implementation utilized an Intergraph TDZ 2000 GT1 with dual Pentium II 400 processors, 512 Megabytes of RAM, three VX-113 graphics cards, and a geometry accelerator (Figure 3).

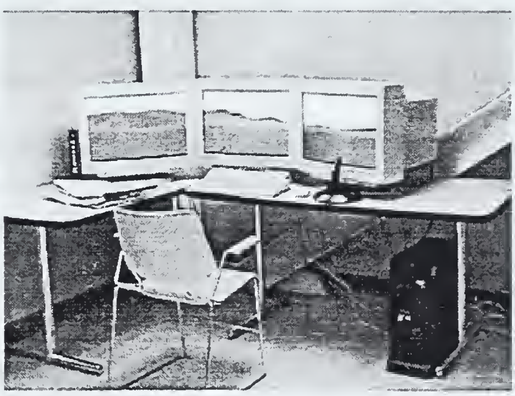

Figure 3. The MITAVES II System.

With all three screens active, the desktop resolution is 4080 X 786. This stems from each 16:9 aspect ratio monitor having a resolution of 1360 X 768. In May 1999, Intergraph Corp. came out with improved graphics cards so the graphics subsystem was replaced. The three VX-113 cards were upgraded to Intergraph Wildcat 4000 cards. The functionality achieved from this upgrade was on-board geometry accelerators for each card and an increase in texture memory from 16 to 64 Megabytes of memory.

b. Software and Data Formats

All software and data used to build the terrain are unclassified. The software used for terrain generation was the commercial product MultiGen-Paradigm, Inc.'s Creator. The runtime environment is MultiGen-Paradigm, Inc.'s Vega version 3.2, which is also a commercial product. The data formats used for the terrain model are also unclassified. The elevation data is DTED Level 2 and the imagery used for the texture is CIB5, both of which are unclassified.

2. The System Must Comply with IT-21 Standards

The hardware described in section IV.1.a exceeds the minimum level specified by IT-21 standards. This should be no surprise since the latest hardware standards specified by the IT-21 are over two years old. MITAVES II executes in Microsoft Windows NT 4.0 thus the operating system is also in compliance. In keeping with the collaborative spirit of IT-21, the hardware is commercial off the shelf (COTS) and standard NIMA map and terrain data formats are used.

3. The System Must be Deployable

MITAVES II's tower case is no larger than a standard full size computer tower so the computer is deployable. The current implementation of the MITAVES II system uses three 24-inch wide aspect ratio monitors. Each monitor measures 22 inches across and

weighs approximately 75 pounds. The weight and size of the monitors is not considered deployable and the large footprint of the monitors takes a six foot table to hold them all. Deployability is perhaps the weakest part of the system because of the difficulty of moving and storing the monitors. An ideal implementation would include the use of lighter weight and much thinner flat panel monitors. The reason they were not used in the current implementation is because the price of each monitor was too expensive. As prices continue to drop for computer hardware, flat panel monitors could become a viable and affordable solution for a deployable system.

4. The System Should Not Need a System Administrator for General Use

A system administrator is not required to run the simulation for the student. Once students log in with an account that is available to everyone, all that remains for students to do is double click on the only icon that is available on the Windows NT desktop. This launches the MITAVES II system. The account for students to log in with is conspicuously displayed with a yellow piece of paper taped to the top edge of the middle monitor. There is no maintenance associated with using the system. Data files are stored on the drive MITAVES II is installed on. Data directories or folders are created in the MITAVES II data folder automatically so there is no need for an administrator to create a new folder for each student who wants to use the system.

5. The System Must Use an Open Systems Structure

MITAVES II uses an open programming development environment so it is possible to include the capabilities for mission planning and mission rehearsal. With more time and programming, MITAVES II can easily evolve into a mission rehearsal system by analyzing the output data files from FalconView, the popular mission planning

software in the Navy Portable Flight Planning Software (N-PFPS). The mission planning output files from FalconView would be incorporated into MITAVES II by plotting the planned route and allowing the user to visualize and fly through the route in three dimensions before the mission is actually executed. The data format for the terrain model uses the industry wide OpenFlight standard. Also, standard NIMA map products are used for the preparation map media and to create the digital maps used by MITAVES II.

6. The System Should be Based in Real-Time

MITAVES II is a real-time based simulator. Equations are used in the motion model to ensure that the simulation speed is that which is displayed on the airspeed indicator. The time between frames in the simulation is recorded and then the virtual helicopter is moved the required amount using physically based modeling equations. Care was taken to ensure that the orientation of the map's true north was the same as the simulators true north. This way, when the user turns to 090 on the HUD's heading indicator the map is oriented to the east as well. Frame rates for the MITAVES II system are above the minimum 8 Hz required for smooth motion. There is no jerky motion observed while the helicopter moves through the virtual environment.

B. INTERFACE REQUIREMENTS

1. The Trainer Must be Easy to Use

The learning curve for using the MITAVES II system is very shallow. Through usability testing, students have been able to walk up and use the MITAVES II system with little up front training.

The program begins with a Visual C++ graphical user interface, shown in Figure 4, that was designed for selecting a route. Four routes were planned for use in the trainer.

If the MITAVES II system is used frequently, four routes may not provide enough variety and pilots may become too familiar with the routes. To alleviate this problem, a checkbox is provided on the interface to allow the user to chose to start at the opposite end of the selected route. This provides a total of eight routes and prolongs the training value of the system.

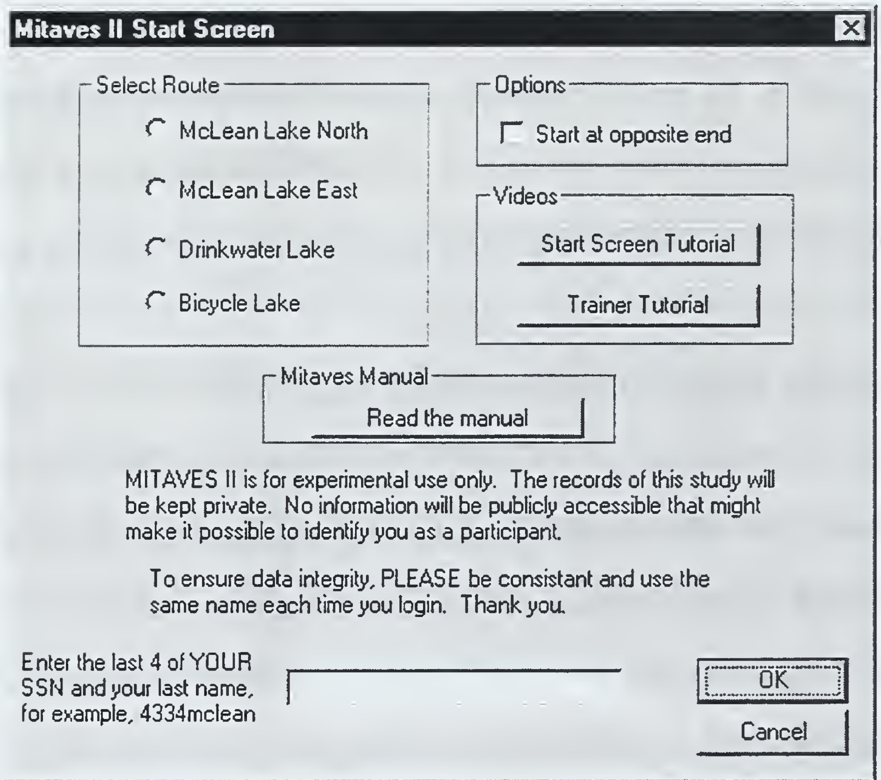

Figure 4. The Graphical User Interface.

The user must enter a name into the edit box. The name is used to keep track of users and the data they create. Users are asked to enter the same name into the edit box each time they use the system so data pertaining to that user is kept in the same place. Appropriate safeguards are taken to prevent the user from entering a name that is not compatible with file or directory names. The interface then creates a directory in the MITAVES II data directory for the name typed in the edit box. In the user's data

directory, a filename is created and based on the user's name and the route that was chosen. A sufficiently large random number is generated and appended to the filename so the same user will not overwrite previously generated data. If a user enters in a name that already has a directory, the same directory is used.

After a directory and a filename are created for the user, the path to this file is passed to the simulation as an argument. The path is needed so data generated in the simulation, such as the path the user flew, can be written to the appropriate file. Additional arguments include which route to use and the starting point of the route. At this point, the interface is done setting up the parameters for the simulation and the GUI is closed.

Three types of help are available for the MITAVES II system. The first help support system is the standard paper manual. The manual details how to get started and how to use the system. The manual and includes diagrams and pictures as well. The next two MITAVES II training mediums are available through the user interface itself. As manuals tend to get lost or damaged, built in help is provided on the interface in the form of Quicktime movies. Two buttons are provided to start instructional videos. The first video describes the interface for starting the trainer. Every button, checkbox, and edit box is described exactly as it is described in the manual. The second movie describes the simulation itself. Every control and key-press required for manipulation of the MITAVES II system is described in the video exactly as the manual describes them. With the inclusion of these two videos, a hardcopy of the manual is not required. Lastly, if the user clicks the appropriate button on the user interface, an electronic copy of the manual is presented in Adobe's Acrobat Reader.

To lower the learning curve further, stickers describing the functions of keys on the keyboard are placed on the keys themselves. Instead of the user having to memorize that pressing the "L" key on the keyboard will bring up the virtual map in the simulation, a sticker is placed over the "L" key that says, "MAP." Every key that has a function in the trainer is labeled. The joystick is labeled in the same manner. Every button on the joystick that has a function in the trainer is identified for quick reference.

2. The Trainer Must be Easy to Control

a. Motion Model

All aspects of the motion model were designed to be as simple as possible. Usability studies were used to analyze assumptions made about the motion model so the user would not have a difficult time controlling the virtual helicopter in the simulation.

Because this application's main goal is to train helicopter pilots to navigate from contour maps, there are no flight dynamics built into the simulation. This trainer is not intended to train helicopter maneuvers during terrain flight so it was determined that the motion model should remain as simple and easy to control as possible. The user's control of the viewpoint in the simulation resembles flying a magic carpet rather than a helicopter.

Altitude may be increased or decreased while flying, however, altitude remains constant as a simple form of terrain following is implemented. As the aircraft flys over the terrain, the aircraft's altitude relative to the terrain remains the same no matter what type of terrain is encountered. This means that the user will never crash into the ground at any altitude that is selected. This allows the student to accomplish the tasks of flying and navigating at the same time without worrying about crashing the aircraft. Altitude can be changed to a minimum of 50 feet and there is no maximum altitude.

Roll is limited to 30 degrees angle of bank for easier control of the aircraft. The maximum roll is encountered when the joystick is moved to the maximum lateral displacement. The rate of turn used is also varied with the angle of bank. The more angle of bank the faster the turn. The maximum rate of turn was determined by user comfort and feedback during usability testing. The rate of turn needed to be fast enough so a sharp turn could be accomplished but slow enough so small corrections to heading could be made.

The decision to give the user the ability to change the aircraft's pitch came as a direct result from usability testing. As the aircraft comes to particularly steep terrain, the horizon is lost as only the terrain fills the field of view. This is due to the aircraft flying so low to the ground and remaining in a level attitude. However, as the aircraft is pitched up in this situation, the horizon, as well as the top of the high terrain, can once again be seen. This allows the user to continue to navigate instead of blindly flying up the high terrain. The reverse holds true when coming down from steep terrain. If the aircraft remains in a level attitude at the top of the terrain, then only sky will be seen as the terrain goes out of view below the aircraft. Pitching the nose down allows the terrain to come back into view and navigation can continue.

The user selects velocity with the throttle on the joystick. For any given velocity, the distance moved is determined by multiplying the selected velocity with the recorded time between frames. This method allows for real-time movement of the aircraft over the terrain.

b. Usability Testing for Joystick Controls

An experiment was conducted to see how pilots who were presented with a PC version of a stick and throttle actually used the controls to move themselves. When

pilots are flying the training aircraft, they are instructed how to move the aircraft with the controls that are present in that aircraft model. Different aircraft have different controls. Helicopters have a cyclic and collective, jets have a stick and throttle, while a yoke and throttle control large multi-engine planes. The experiment was designed to see how pilots with different aircraft model backgrounds reacted to a common control interface.

A Thrustmaster Flight Control System (FCS) Mark I joystick and a Thrustmaster Weapons Control System (WCS) Mark I throttle quadrant (Figure 5) were placed on a table with the joystick cords hanging off the back of the table.

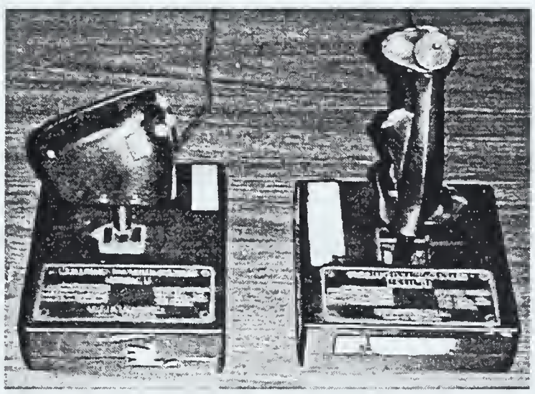

Figure 5. Thrustmaster FCS and WCS.

Subjects were students at the Aviation Safety Officer School at the Naval Postgraduate School. The students were used as subjects because they were pilots who had recent flying experience. Most pilots attend this school while they are in a current flying billet and since they were tested in the fifth week of the course, most had less than 6 weeks since their last flight. The subjects were asked to sit down in a chair positioned behind the stick and throttle and asked if they were a fixed wing pilot or a rotary wing pilot. They were also asked how long it had been since their last flight. Next, the subjects were asked to place their left hand on the throttle and their right hand on the joystick. With their hands on the controls, the subjects were asked to imagine themselves

hovering in one place on a magic carpet. The administrator of this experiment, who was standing next to the subject and facing the same direction as the subject, put his hand out flat (palm down) and then raised his hand up toward the ceiling. While doing this, the subject was asked to raise his magic carpet up towards the ceiling by moving the controls. The subjects' movements of the controls were noted. If the subject moved more than one control at a time, for example, the joystick forward and the throttle back, the subject was asked to repeat the task moving only one control. In the same manner, the subject was asked to move his magic carpet down from the ceiling, forwards to the front wall, backwards to the rear wall (while facing forward), left, and finally to the right in that order.

Eighteen male subjects were tested with the results shown in Figure 6. The table shows that eight subjects moved forward by pushing the throttle forward and moved up by pulling back on the joystick. Ten subjects moved forward by pushing the joystick forward. Half of these subjects moved up by pulling the throttle back and the other half moved up by pushing the throttle forward.

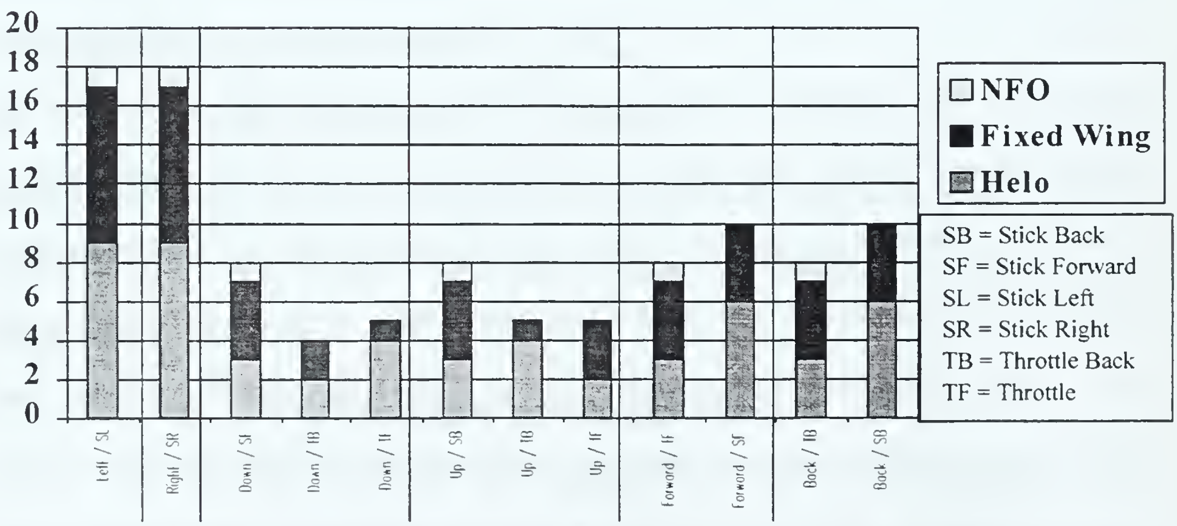

Figure 6. Results from Joystick Testing Experiment.

These results show that asking pilots to imagine moving in a three dimensional world with a separate joystick and throttle produces mixed results. The subjects could not seem to agree on how to represent three axes of motion with a two axis joystick and a single axis throttle. With the x-axis as the left / right axis, the y-axis as the up / down axis, and the z-axis as the forward / back axis, subjects can not agree on how to move in the y-axis direction. There is full agreement for moving left and right along the x-axis because that is the only axis aligned in that direction. When asked to move up, however, the subject must choose to move either the z-axis on the joystick, or the z-axis on the throttle.

One would think that fixed wing pilots would choose to pull the stick z-axis back to move in the up direction because doing so in a fixed wing aircraft pitches the nose in the up direction thus increasing the aircraft's altitude. However, only half of the fixed wing pilots chose this option to move up. Helicopter pilots increase their altitude in a hover by using their left hand to pull up on the collective. Since there was no joystick or throttle y-axis to choose from, there was no consensus among helicopter pilots to choose one particular z-axis.

These results suggest that no matter how the joystick was configured for the MITAVES system, about half of the users would initially feel uncomfortable with the controls causing some adaptation. For this reason, the simplest device for controlling the virtual helicopter was chosen. The original MITAVES used a BG Systems Flybox for the human computer interface. The designer of the original MITAVES thought that altitude control should be done with the joystick z-axis and the smaller lever on the left should control movement forward and back.

There are a limited number of consumer level interface devices developed for UNIX systems because so few UNIX systems are used for home entertainment. On the other hand, the PC market is flooded with many different interface devices. Most joysticks today have a throttle built into the side of the joystick's base. As joysticks for PC games are mostly used to control flight simulations, the throttle on the joystick usually is configured to increase the thrust of the aircraft making it move forward. For this reason, the MITAVES II joystick is configured so the throttle of the joystick moves the helicopter forward. Since MITAVES II was intended to be flown at a fixed altitude, neither the stick nor the throttle was assigned to increase the altitude of the virtual helicopter. Instead, the hat switch positioned on top of the joystick was configured to increase or decrease the altitude of the aircraft. Since the hat switch is roughly aligned in the up and down directions, the switch can be intuitively used to control the aircraft's altitude. The joystick in MITAVES II is configured more like a cyclic on a helicopter. Moving the stick left or right rolls the aircraft in that direction while moving the stick forward and back pitches the aircraft fore and aft respectively. The Microsoft Sidewinder Pro joystick is depicted in Figure 7.

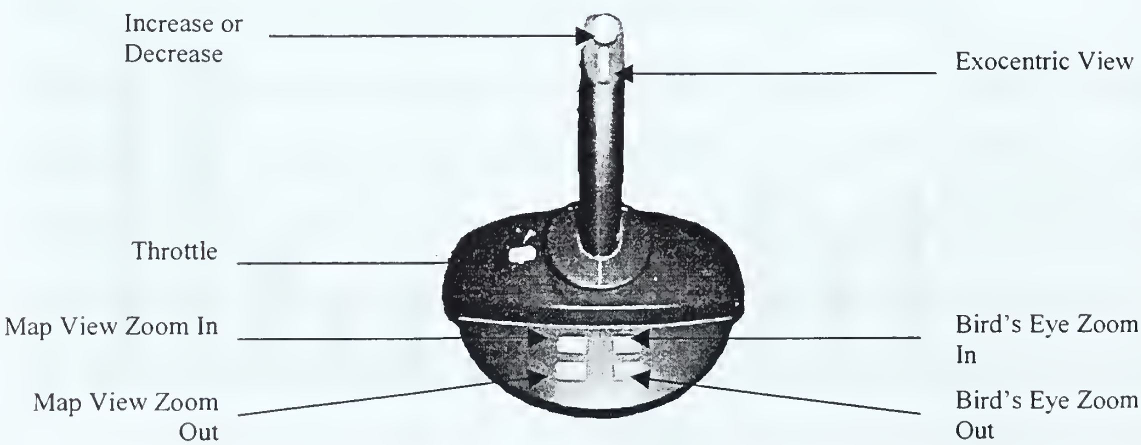

Figure 7. The joystick and its functions in the MITAVES II system.

3. The Trainer Must have a Wide Field of View

As previously stated, a computer based trainer for teaching navigation must have a wide field of view. The current implementation of the MITAVES II system has a field of view of 140 degrees. This large field of view is achieved by using three 24-inch 16 X 9 aspect ratio monitors. Although the footprint is rather large, the field of view is quite impressive. Each monitor has a measured field of view of 42 degrees when users sit approximately 27 inches from the center monitor. Because the monitor screens do not physically touch one another, an additional 7 degrees was added to account for the plastic frames around each screen.

A resolution of 1360 X 766 is provided to take advantage of the 16 x 9 aspect ratio monitors. Since a three screen configuration is used, a total desktop area of 4080 x 766 is utilized. Each monitor is allocated a separate simulation window. So instead of having one large 4080 X 766 window, three separate windows are created; one for each of the monitors. This was done for performance reasons. When windows overlap the monitor screens, for example when an active window is split between two or more monitors, the frame rate of the application within that window drops. This is due to the application having to be rendered twice, once for each graphics card. Because of this, one 1360 x 766 window is created per monitor. Each window has its own graphics channel. The center channel has the normal one screen viewing volume with a horizontal field of view of 42 degrees. The left channel is skewed 49 degrees to the left, and the right channel is skewed 49 degrees to the right. An additional rotation of 7 degrees is required per offset channel because the frames of the monitors do not allow the screens to

touch. Trial and error was used to determine the amount of additional rotation until the terrain was flowing smoothly between each of the screens during a constant velocity turn.

Windows for two additional views are created and rendered in the left and right channels. These windows are the map view and the bird's eye view respectively. They are created as orthogonal viewing volumes because they are top down views of flat surfaces. This configuration makes it possible to move the viewpoint closer and farther away from the surface of the texture giving the user the ability to "zoom" in and out. The viewpoint of these windows is moved an amount corresponding to the distance the player is moving through the terrain.

4. Available Flight Information

Heading, barometric altimeter, radar altimeter, airspeed, pitch, roll, and angle of bank are provided to the user via a Heads Up Display (HUD). The HUD is shown in Figure 8.

Figure 8. The Heads Up Display.

The airspeed gauge is provided to give the user the aircraft's velocity relative to the terrain. Although velocity is portrayed correctly, it appears much slower due to limitations of the resolution of the texture. The first generation HUD implemented a box with a number inside as the sole means for determining velocity. Even though the number representing the velocity was completely obvious on the screen, users still complained that it looked like they were moving very slowly. Because of this, the

number was replaced with a dial that looked like an actual aircraft airspeed indicator. The airspeed indicator's maximum velocity is 120 knots because this is the maximum speed a student would be expected to travel during a training flight. Actually, at 120 knots, a novice student would not be able to navigate effectively. All training flights are flown between 60 and 90 knots, which is considered to be a reasonable training speed. The dial around the airspeed gauge is color coded to provide quick feedback to the user about velocity. From zero to 90 knots, the outside of the dial is colored green. From 90 to 120 knots the dial is colored red. The red color tells the student that the current velocity is not recommended for training. The dial also gives feedback as to the relative velocity that the aircraft in the simulation can achieve. Since it looks like the needle on the dial is close to the maximum velocity at 90 knots, the user may think that the proper velocity in the simulation has been reached, even though the terrain's texture makes it appear as if the user is moving much more slowly.

Two different types of altitudes are given. The first is altitude in mean sea level and is provided by a barometric altimeter. This altitude gives the user feedback about how high the aircraft is relative to other mountainous terrain. For example, if a mountain peak is depicted on a map to be 4000 feet MSL, then the user could use the information that the aircraft is at 3500 feet MSL to determine that the aircraft is 500 feet below the top of the peak.

The second altitude is given as height above the terrain and is provided by a radar altimeter. Training for terrain flight is conducted between 50 and 200 feet above the ground. For example, an aircraft could be at 3500 feet mean sea level and only be 50 feet

above the ground. The height above the terrain needs to be provided because this information is not readily apparent from the barometric altimeter alone.

Heading is represented on the HUD as a 360 degree rotating dial. The dial is numbered in 30-degree increments from 0 to 360. As the aircraft's heading changes, the dial rotates so that the heading is represented at the top of the dial. A dial is used instead of a number in a box so the user can use the dial as a tool for increasing situational awareness. When a dial is used, the student can quickly determine headings 45, 90, 135, 180, 225, 270, and 315 degrees off of the base heading through the use of permanent tick marks on the heading indicator.

A horizon indicator in the lower middle section of the screen provides information on the aircraft's attitude. This indicator is important because the user is allowed to increase and decrease the aircraft's pitch. If the pitch is changed, the user will need to know when the aircraft is brought back to a level attitude and the horizon indicator provides this information. The horizon indicator also shows angle of bank when the aircraft is in a left or right turn. Roll is expressed in terms of angle of bank and is displayed in the center box below the horizon indicator. A small upside down triangle that rotates around a graduated ring on the bottom of the horizon indicator also provides roll information. Unless the aircraft is in a turn, the roll is zero. The joystick is self-centering so releasing the joystick will position the aircraft so that there is no roll.

C. METHOD REQUIREMENTS

Sullivan's research is the basis for the core tools used in the MITAVES II system. As the name of the system suggests, this is a second generation of Sullivan's MITAVES system. Although the differences between the systems' hardware are significant, the

changes in the training aids of the two systems are relatively minor. Most of the changes result from more capable hardware being able to handle the increased resolution of the data.

1. The System Must Train the Tasks of Map Interpretation and Terrain Association with 1:50,000 Scale Contour Maps

Interviews with students and instructors at HS-10 suggest that some sort of exocentric viewpoint and a "you are here" map are key tools for students to use in navigation training (Sullivan, 1998). The MITAVES II implementation of these tools is almost exactly the same as the MITAVES system.

a. Exocentric viewpoint

After experimenting with several different representations of an exocentric viewpoint, Sullivan finally decided on an implementation that minimized the disorienting effects of teleportation while maximizing the benefits of a top down viewpoint. As the exocentric viewpoint is activated, the camera is detached from the normal position inside the cockpit. When the controls are manipulated, the camera is then moved up and away from the helicopter in a fluid and animated motion. To minimize disorientation, the camera is always looking at the helicopter. The exocentric viewpoint is demonstrated in Figure 9. The only two differences between the current implementation and Sullivan's are the angle that the camera is moved away from the helicopter and symbology used when the helicopter disappears from view. Sullivan uses a 10-degree slope while the current version uses a steeper 25-degree slope. The reason for the change stems from the aspect ratio of the monitors. Since a wider aspect ratio is currently used, the slope had to be made steeper so that the helicopter would remain in the middle of the screen when the exocentric view is activated. A shallower angle resulted in the helicopter appearing

towards the bottom of the screen during exocentric views. The symbology was changed from a circular icon to a triangular one. The top point of the triangle points in the direction of travel. The icon placement is directly on top of the helicopter vice above it like in the MITAVES implementation. By placing the icon directly on top of the helicopter, students can better correlate the triangle representation to their position.

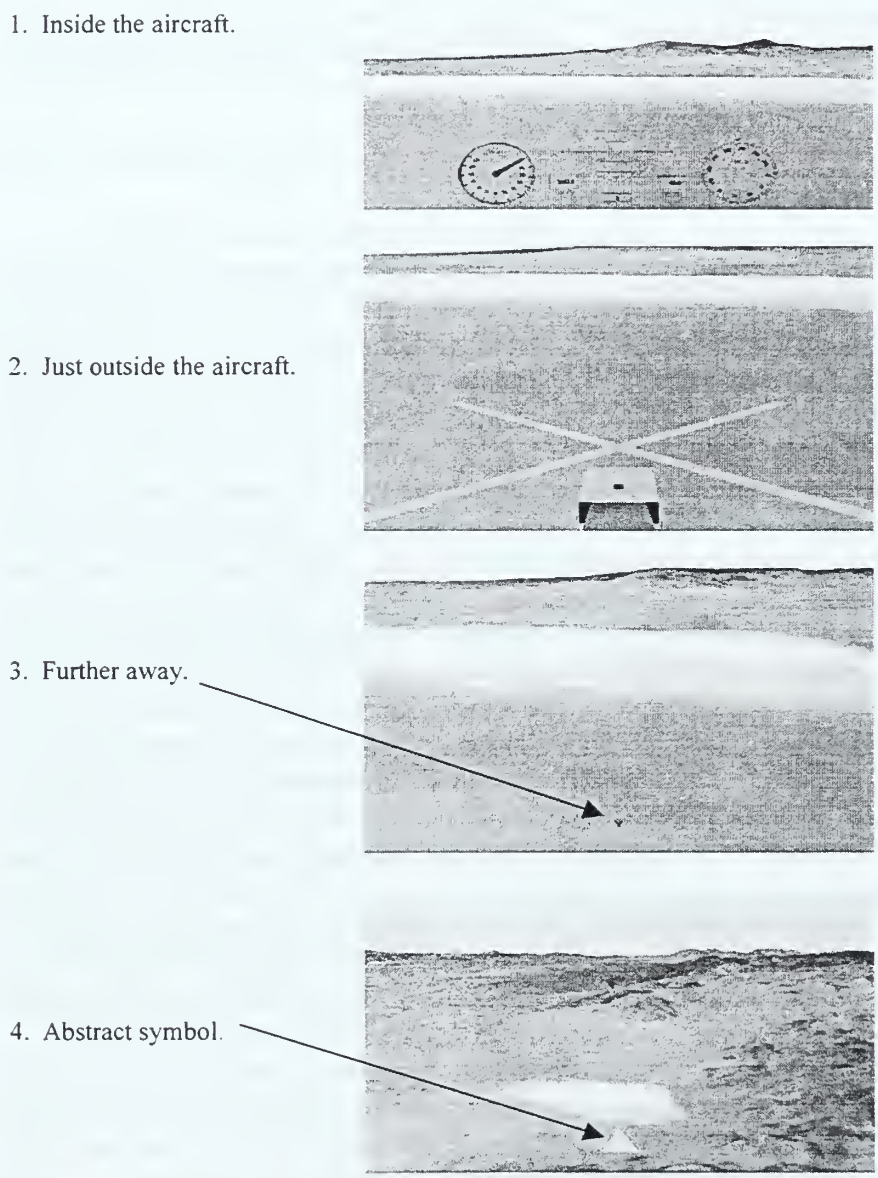

Figure 9. Demonstration of the Exocentric View.

b. You are Here Map

A "You Are Here" (YAH) map is implemented exactly the same as the original system. When activated by the user, a digital representation of the map the student is navigating from is rendered in a window on the left monitor. The YAH map is shown in Figure 10.

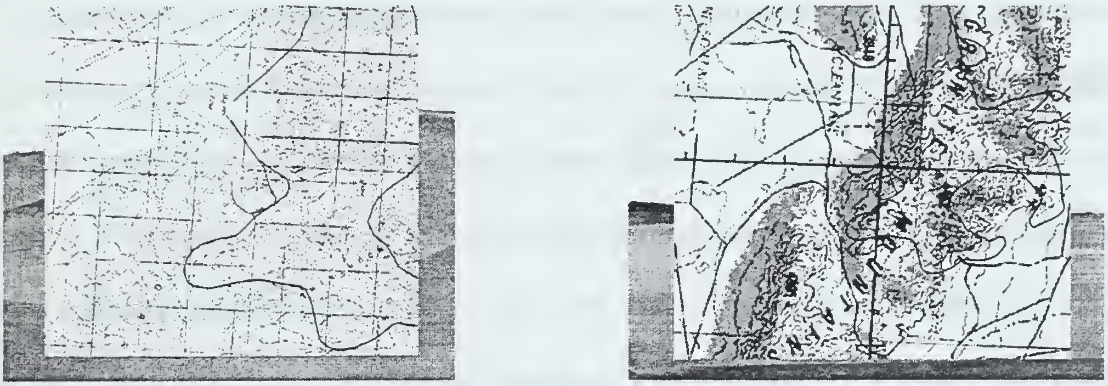

Figure 10. The 1:50,000 scale (left) and 1:250,000 scale (right) You Are Here maps.

A black line represents the route the student is to follow. The path the student has actually flown is shown as a red line. By comparing the two lines, students have immediate feedback relating to their performance. Students can zoom the viewpoint of the map view for closer inspection of the route or to get the big picture of the entire route. With a key-press, the user can switch map scales between 1:50,000 and 1:250,000.

Corypheus Software's Easy Terrain generated the maps used on the original system. What was advantageous about these maps was that they represented the terrain exactly as shown in the VE. The program generated maps that had contour lines for every terrain feature that was represented in the VE. However, these maps were not standard NIMA products. There was no additional color added for different terrain heights and there were no words or grid lines that gave an indication of grid north. This made reading these maps more difficult than the standard 1:50,000 NIMA product. In

addition, standard NIMA products are the only maps used in the aircraft when pilots fly real world missions. For these reasons, it was decided to use the standard NIMA map for this project.

The limitation of using NIMA maps for MITAVES II is that terrain represented on the maps was not always present or was distorted in the VE. If the user was trying to use subtle changes in terrain elevation for navigational purposes, the user may be trying to look for cues in the VE that were not represented. To account for this, the routes were chosen so that major terrain features were used, vice minor terrain features that may not be correctly represented in the VE. Another limitation is that cultural features were represented on the maps however, no cultural features were represented in the VE. Therefore, key manmade features, such as power-lines, towers, quarries, or large buildings that may be used as cues for navigation were not represented with three-dimensional objects. Some of these features were represented in the texture but only on a limited scale. For example, trails were visible as narrow lighter areas in the texture when viewed at low database altitudes. Likewise, roads were narrow darker areas. Although these limitations are present, they are actually good for training. Student pilots are taught not to rely on man-made features when navigating. This is because man-made features can be destroyed in combat. Pilots less reliant on man-made features are more adept to handle situations when depicted cultural features are not present in the real world.

In addition to the above, the following tools were added to the current implementation of the MITAVES II system: bird's eye view and viewpoint rotation. Upon further analysis of the map interpretation task, these tools were developed in order

to enhance the system's ability to teach the task of map interpretation and increase a student's situational awareness.

c. Bird's Eye View

When students press the "D" key on the keyboard, they can bring up a window with a bird's eye view of their position. The bird's eye view is shown in Figure 11. The view starts out approximately 5000 meters directly above the current position and looks straight down at the helicopter. This view can be zoomed in and out in order to place the exact position of the helicopter relative to the route and relative to the entire database. What is unique about this view is that the user can quickly switch between the bird's eye view and the contour map.

Figure 11. The user can switch the Bird's eye view with the map view.

This may be proven to be useful in teaching the student how to interpret the contours on the map to the terrain that the map represents. When viewing the bird's eye point of view, it is easy to identify high mountainous terrain, low lying areas, roads, trails, and dry lakebeds. These features are also prominently shown on the contour map. By quickly switching between the map and the terrain, the user can see how the map correlates to the satellite imagery representation of the real world terrain. Likewise, the user can correlate the imagery to the map. As with the other tools available to the student

during the simulation, the motion of the helicopter is frozen so this view may not be used as a moving map.

d. Viewpoint Rotation While Viewing the Map or Bird's Eye Views

While either the map or the bird's eye view is displayed, if students were to move the stick to the left or right, a rotation is accomplished in the same direction. As the turn is made, the egocentric point of view, the map, and the bird's eye view are all rotated the same number of degrees. This is useful for obtaining a bearing to prominent navigation features. The helicopter would be turned so that the feature is directly in front of it and then the bearing is read from the heading indicator. As the map and bird's eye views are turned off, the viewpoint is rotated back to the user's original heading and then the simulation is resumed.

e. Egocentric Motion While the Tools are Used

All egocentric motion is stopped while the above tools are activated. If a tool is used, the motion of the virtual helicopter is halted. Students can then use the tools for as long as they want and not have to worry about flying the helicopter. This allows students to fully concentrate on using the tools for orientation.

Another reason motion is halted is to minimize the reliance on the tools as a means of navigation. For example, if the YAH map was allowed to be activated while flying, students may focus their attention on that rather than interpreting their paper map to the virtual terrain. If this were the case, students may simply trace the routes on the YAH map with the map's helicopter icon. Although the student would score very well in the end because their flight path would exactly match the route they were supposed to fly, the students' map interpretation and terrain association skills would never increase. In

fact, they may actually decrease because the system would give the student a false sense of security that reinforces the negative training behavior.

2. The System Must Provide User Feedback

All four of the tools in the previous section provide the user with useful orientation feedback. The YAH map and the bird's eye view both provide information related to the student's flight path over the terrain. When this information is compared to the actual route information that is also depicted, students can immediately tell whether or not they are on course. This feedback is key to keeping students oriented if they become lost.

The exocentric view provides students with spatial orientation feedback. When students move their viewpoint away from the helicopter, they can see the surrounding terrain and their position in it. This helps to increase students' situational awareness and spatial orientation.

The viewpoint rotation tool gives a bearing to any feature that the virtual helicopter is pointed at. This feedback is useful for orientation in relation to grid north and to terrain features in the immediate vicinity. If students have a sense of where north is, then they can use their mental depictions of turns along the route to make correct navigational decisions.

3. The Trainer Must Record a History of the Training Event

A history of every training event is recorded to a file for later analysis. The data file has a record of the students flight path in terms of x, y, z, heading, pitch, roll, and speed. In addition, simulation time is also recorded. To fully understand how students used the trainer, an event is recorded to the file every time one of the tools is activated

and deactivated. For example, when the exocentric view is triggered, an event is recorded to the file. When the exocentric view trigger is released, another event is recorded. Since simulation time is also recorded with each event, later analysis can determine exactly when the exocentric view was activated and the duration of its use. These data files are also used when the students' track is drawn while the YAH and bird's eye view maps are activated.

D. TERRAIN MODEL REQUIREMENTS

1. A High Fidelity Model Must be Used

a. Terrain

The terrain database was created with MultiGen-Paradigm, Inc.'s Creator software. First, Digital Terrain Elevation Data (DTED) Level 2 data produced by NIMA was converted from its original format to MultiGen-Paradigm, Inc.'s proprietary Digital Elevation Data (DED) format.

Digital Terrain Elevation Data (DTED) is a uniform matrix of terrain elevation values. It provides basic quantitative data for all military systems that require terrain elevation, slope and gross surface roughness information. Data density depends on the level produced. DTED 0 post spacing is 30 arc seconds (approximately 1000 meters). This corresponds to a small-scale hardcopy product. DTED 1 post spacing is three arc seconds (approximately 100 meters). This corresponds to a medium scale hardcopy product. DTED 2 post spacing is one arc second (approximately 30 meters), corresponding to large-scale hardcopy products. (NIMA, 1998)

The MultiGen-Paradigm, Inc. software required the conversion from DTED 2 to DED. DTED 2 was chosen because it was the highest resolution unclassified elevation data available.

After the conversion, a gaming area was chosen. The gaming area had to be large enough so the end of the gaming area could not be seen. Also, sufficient mountainous terrain had to be available for interesting terrain flying. For the above reasons, the Fort Irwin reservation was selected. The latitudes and the longitudes of the gaming area are shown in Table 2.

NW corner	NE corner
35~38'00"N	35~38'00"N
116~57'00"W	116~17'00"W
SW corner (origin)	SE corner
35~15'00"N	35~15'00"N
116~57'00"W	116~17'00"W

Table 2. Latitudes and Longitudes of the Gaming Area.

These points correspond to an area 42599 X 60498 meters giving an area of approximately 2,577,154,302 square meters.

Next, the number of polygons was chosen. The real-time system that the model was to be rendered with was considered, as was the resolution of the terrain itself. The first attempt was to build a database with 5000 polygons. However, 5000 polygons did not provide enough relief between elevation posts. Ridges and valleys within mountainous terrain were not accurately portrayed because they were lost while the software tried to decide how to best represent the data with too few polygons. This resulted in a terrain model that did not represent all the features found on a 1:50,000 scale contour map. The next model was built with 8000 polygons and was barely acceptable

for terrain recognition as defined in Section III.D. The last model was built with 50,000 polygons. A four processor SGI Onyx Infinite Reality worked eight hours to complete the model. No levels of detail were incorporated into the model at this point. The polygon terrain skin itself is not acceptable for terrain recognition training as defined in Section III.D, however, draping the terrain skin with satellite imagery as a texture dramatically increases the terrain database's value for training. The reason for this is that the shadows on the texture fool the eye into thinking valleys, ridges, and dips are actually built into the model when the are not. The texture, therefore, made it easier for students to correlate these features to the map.

b. Texture

The texture comes from Controlled Image Base (CIB) five-meter imagery produced by NIMA. Five-meter Controlled Image Base (CIB5) is an unclassified / limited distribution seamless dataset of orthophotos made from rectified grayscale aerial images collected from national sensors and degraded, resulting in a ground sample distance (resolution) of five meters. CIB data is produced from digital source images and are compressed and reformatted to conform to the Raster Product Format (RPF) standard. CIB files are physically formatted within the National Imagery Transmission Format (NITF) message. Applications for CIB include rapid overview of areas of operations, map substitutes for emergencies and crises, metric foundation for anchoring other data in C4I systems or image exploitation, positionally correct images for draping in terrain visualization, and image backgrounds for mission planning and rehearsal. (NIMA, 1998)

NIMA's MUSE tools, in particular, the Rastor Importer, takes raw CIB data and produces a digital photograph in standard graphics format. Since the data was

CIB5, every pixel represents five meters on the ground. Measuring the area of the gaming rectangle, and dividing by five yields the correct number of pixels for an RGB formatted graphics image. Unfortunately, it also produces a black and white texture over 100 megabytes in size. Adding color to the texture for a more realistic environment produces a 300-megabyte image. As a compromise, a 2048 x 1024 image was used. This yielded a 6-megabyte image after color was added. Using larger textures usually caused the modeling software to crash. As a work around for large textures, a mosaic utility was used to cut up the texture into 1024 x 1024 chunks. These chunks are created as separate files and then used to tile the textures into the appropriate place on the gaming area.

Since the texture was black and white, color was added so the virtual environment would seem more realistic. Adobe PhotoShop 4.0 was used to add this color. A brown hue was decided upon because it seemed the most realistic for the area and it was easy to implement using PhotoShop's colorize feature. After several attempts a light brown hue was finally found that seemed to provide a nice balance between the darker mountains and the whiter dry lakebeds.

Also, the CIB image inherited two darker strips of overexposed areas where the satellite overlapped on successive data collection runs. These strips had to be removed because they were distracting to the user during higher bird's eye views. PhotoShop's rubber stamp tool was used to remove the dark strips leaving a barely noticeable strip of repeated texture.

The texture was applied to the terrain skin using Creator's four point put method. This method matches the four corners of the texture with the four corners of the terrain skin and automatically applies the texture to each polygon of the terrain skin.

Since the terrain and the texture were generated using the same latitudes and longitudes, the geographical features of the texture matched up the corresponding peaks and valleys of the terrain.

E. TESTING AND EVALUATION

An experiment was developed to ensure that the MITAVES II system improves navigational performance in the air. The experiment and the results of that experiment are covered in the next chapter.

V. EVALUATION

An experiment was conducted to evaluate the effectiveness of MITAVES II as a tool for training map interpretation and terrain association. The MITAVES II system was taken to Helicopter Antisubmarine Squadron 10 (HS-10), which is the squadron that trains fleet replacement pilots for the United States Navy. HS-10 receives aviators from flight school in Pensacola, Florida and trains them how to fly the SH-60 helicopter. HS-10 is also responsible for introducing students to the mission of Combat Search and Rescue (CSAR).

A. EXPERIMENTAL SETUP

1. Subject Pool

HS-10 was chosen as the testing squadron for two reasons. First, a rapport with the squadron was established since the testing of the original MITAVES was conducted there. The instructor pilots knew of the original experiment and were eager to help with the second experiment.

Secondly, the students at HS-10 are all roughly equal in flight and terrain navigation experience. Students have roughly 200 flight hours at the completion of flight school. Their navigational experience is gained from three 2-hour training flights over relatively flat terrain in the areas surrounding Pensacola. Since the students all have a common background with little navigational training, they are a good choice for subjects in this experiment.(Sullivan, 1998)

2. Treatment

The experiment was to compare two groups of student pilots. A control group of students who did not get to use the MITAVES II system was the first group while the second group consisted of pilots that used the trainer. Due to scheduling difficulties and

moon lighting cycles, the second group consists of only four students. HS-10 trains approximately 95 students a year so four students is roughly five percent of the annual population of students. These students were given a basic introduction to the MITAVES II system. This introduction showed the students how to log in and select a route as well as how to use the feedback tools available while the simulation takes place.

The experimental group was chosen at random by HS-10 staff. Once chosen, the group was notified that they must use the MITAVES II system before their first navigation training flight in the helicopter. Students had approximately one week notice before their first navigation hop.

The MITAVES II system was designed to be used without an additional operator or technician present. This allowed the students to train as often or as little as they liked and on their own schedule. The system was set up in a quiet corner of one of the training classrooms as shown in Figure 3 on page 33. All of the tools discussed in Section IV.C.1 were available to the student to use to help train the tasks of map interpretation and terrain association.

3. Results

Actual student use of the trainer was mixed. One student used the trainer several times, another used it twice, and the rest only used it once for varying durations. The data files generated by the system were analyzed by plotting the student's track over the route they were supposed to follow. A 200-meter wide corridor was placed over the route. Student tracks outside this corridor resulted in flight paths over 100 meters off of the intended route. The evaluation of the data files was based on a visual comparison of the student's flight track and the route. Students whose flight tracks were closer to the

intended route scored better than students whose routes were outside of the 200-meter corridor. The students' tracks are shown in Appendix B.

In addition to the data files, grade cards were used to evaluate student navigational performance in the air. The grade cards were developed by Sullivan (1998) and used with no additional changes. Ranking of the grade cards was accomplished by determining which students were rated above average as compared to their peers. A student who was rated above average on more of the grade card sections was ranked higher. The grade card is shown in Appendix A and grade card results are shown in Appendix B.

The CSAR curricular officer at HS-10 filled out the grade cards. This IP was the pilot who actually flew with all the students in the experimental group and the control group. This is advantageous because the subjective grading on the grade cards is consistent, as he was the only one grading the students. By using only one evaluator, the confounds that are inherently present when using several evaluators are greatly minimized.

On the other hand, the argument can be made that the entire analysis is based on one person's opinion. To counter this, one must look at the population of students available for training and the instructors available to train them. Roughly 100 students are trained annually at HS-10. The subject pool for this experiment was 10 students or 10 percent of the annual population of students. So the instructor was basing his opinion against all of the students who he had flown navigation flights with, which is greater than 10 percent of the annual student population. Roughly one-third of the pool of available

IP's are qualified TERF instructors. Since we are dealing with a limited population, there are not that many opinions to evaluate the system in the first place.

Based on the results shown in Table 3, three out of four of the students who received training prior to their navigation flight in the helicopter earned higher evaluation grades than the students who did not use the trainer. Table 3 also shows a disparity between the "last map rank" and the "rank in air" ratings. For example, Subject 2 had the highest performance in the air, but had the lowest performance on the trainer.

The average grade card score for the 6 students who did not use the trainer is 11.75 out of 20. The average grade card score for the four students who used the trainer is 14.125 out of 20. This difference represents a 12% increase in grade card scores for students who used the MITAVES II system.

Subject	Last Map Rank	# runs attempted	Map Open Count	Switched to JogAir	Switched to 1:50000	Bird's Eye Count	Switched to Map	Switched to Terrain	Help On Count	Exo Count	Grade Card Score	Rank in Air
1	1	2	4	0	0	0	0	0	1	0	16	2
2	4	1	21	2	2	3	0	0	0	1	20	1
3	2	1	12	0	0	4	0	0	1	0	14.5	4
4	3	6	7	0	0	0	0	0	0	0	6	10
5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	11.5	6
6	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9.5	8
7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	14	5
8	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	9	9
9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	11.5	6
10	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	15	3

Table 3. Results from the Experiment.

VI. HARDWARE EXPERIMENT

An experiment was conducted in order to find out the best graphics card for a multi-channel graphics intensive terrain viewing application. Both the operating system and the graphics cards were evaluated. The frame rate of the application was the sole factor in determining which combination of graphics card and operating system was superior.

Consumer level graphics cards were of particular interest. The third generation of graphics cards was released to the public in summer 1999. The latest generation of graphics cards is approaching the capabilities and performance of professional level cards. For this reason, it was to be determined if these cards can run an application similar to MITAVES II with frame rates above eight Hz. Eight Hz is the point that humans perceive smooth motion in simulation applications.

A. SETTING UP THE EXPERIMENT

The experiment was designed to find out which graphics card was the best for the MITAVES II system, therefore, the same terrain database was used. MultiGen-Paradigm's Vega NT software was utilized to create a path through the virtual terrain. The path was chosen so that the flight profile though the terrain matched, as closely as possible, a route that may be used by students when they train with the MITAVES II system. Therefore, the path was a low altitude fly through over prominent terrain features from the terrain database. The same path was used for all the trials in this experiment.

The metric used for the experiment was frame rate. Frame rate was measured in the simulation loop and then reported to the DOS screen. At the end of a run, the frame

rates were averaged to determine the overall frame rate. The overall average was the standard for measuring success in this experiment. The graphics card with the highest average frame rate was considered the best performing card.

B. RUNNING THE EXPERIMENT

Before each trial, the graphics card was installed and the latest drivers for each card were loaded. The resolution was set to 1024 X 768 and the refresh rate was set to 60 Hz. The color resolution was set to 32 bits for Windows NT trials and 16 bits for Windows 98 trials.

The experiment itself was relatively simple. Once the pathing program was started, the automated fly through would begin. Each trial was stopped at the same point in the terrain database, therefore, the same amount of geometry and texture was processed by each graphics card. Then a filename was given to the program and a text dump of the trial results was stored in the file.

Five different graphics cards were used with the Windows NT 4.0 operating system. These cards were the 3dfx Voodoo3 2000 PCI, Nvidia TNT2 PCI, Diamond Viper V770, Intergraph VX113A-T, and Intense 3D Wildcat 4000. The Intergraph and Intense3d cards were not tested with the Windows 98 operating system since there were no graphics card drivers available for this operating system. The latest graphics card drivers were downloaded from the respective company's website just before the experiment was conducted.

The test-bed was an Intergraph GL2 computer. Inside the GL2 is a Micronics motherboard with an Intel Pentium II 400 MHz processor and 128 Megabytes of RAM. As the graphics cards were switched, the standard VGA PCI driver was loaded before installing the driver for the specific graphics card.

Two different trials were performed. The first trial, named "Path 1," was a 1024 X 768 single channel application. The second trial, named "Path 2," was a dual channel application. Each one of the channels in the dual channel application were 512 X 768. An application with dual channels was tested since the MITAVES II system is a multi-channel application.

C. RESULTS AND CONCLUSIONS

1. Windows 98

The Windows 98 operating system was tested in order to find out how consumer level graphics cards performed while running applications similar to MITAVES II. Windows 98 has a built in feature that allows a user to easily install multiple graphics cards and monitors. There was no need to use special graphics card drivers because current Windows 98 drivers are written to be "multi-monitor aware." This means that the multiple graphics cards are automatically configured for use as long as the drivers for that card are loaded.

The graphics cards were tested in both single and dual monitor configurations. One dual monitor configuration included two Voodoo3 PCI cards, while the other dual monitor configuration paired the AGP Viper card with the Nvidia PCI card.

Both Windows 98 dual monitor configurations were poor performers. The highest frame rate achieved with either configuration was 2 Hz. Faster frame rates could be achieved if the size of the windows were made very small. The small window sizes made navigation in the virtual environment impossible.

Windows 98 single screen/graphics card configurations did much better. The frame rates for each of the cards are listed in Figure 12. Since frame rates were all above 25 Hz, Windows 98 can be considered an option for single screen implementations of

terrain applications. The Windows 98 operating system is useful since almost every controller available on the market today supports Windows 98. For example, the Microsoft Sidewinder Force Feedback joystick is supported in Windows 98 but it is not supported in Windows NT.

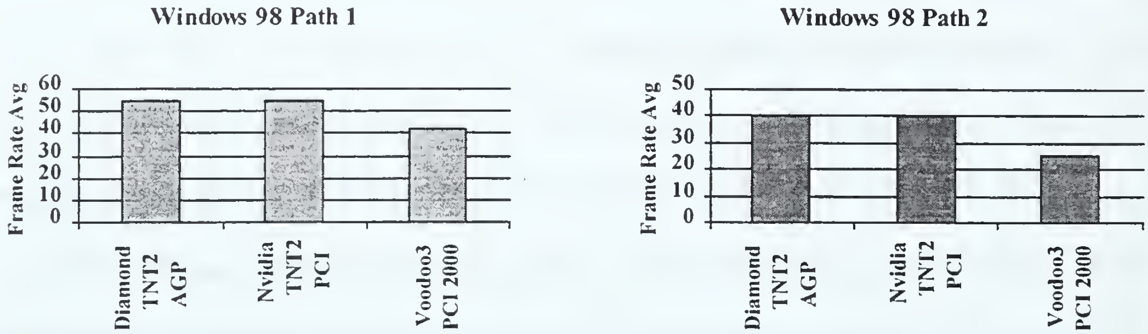

Figure 12. Windows 98 results for single a screen application, 1024 X 768, 16 bit color resolution. The dual channel results are on the right.

2. Windows NT

The test-bed was used to evaluate graphics card performance in single screen configurations with the Windows NT operating system. Windows NT does not natively support multiple monitor configurations. Special graphics cards drivers must be written to take advantage of multiple graphics card implementations.

The results from the experiment are shown in Figures 13. All of the graphics cards had frame rates over 30 Hz except for the Voodoo3 card, which performs very poorly in 32-bit color resolutions. One surprise is that the $150 Diamond card out performed the $2800 Intense3d card by 10 Hz. However, multiple monitor configurations with the Diamond card are available exclusively in Windows 98 where they could not achieve more than 2 frames per second. This leaves Intergraph and Intense3D cards as the sole multiple monitor configuration options because they are the only cards with drivers that directly support this implementation.

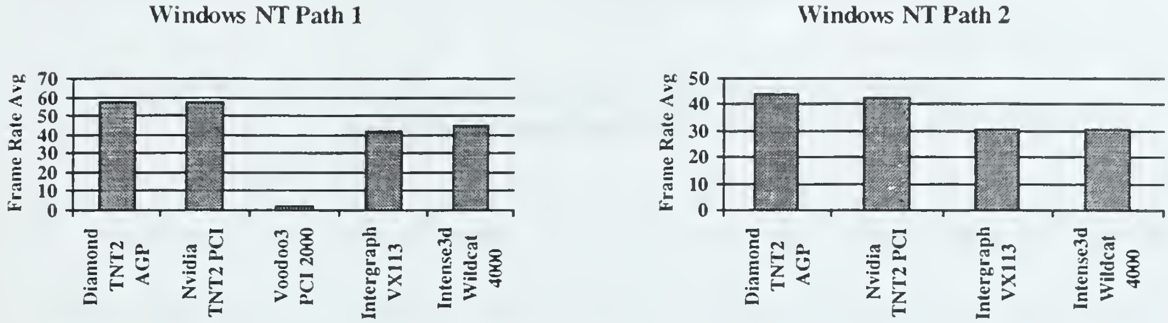

Figure 13. Trial results from the single screen application, 1024 X 768, 32 bit color resolution. The dual channel results are on the right.

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VII. CONCLUSIONS

A. SUCCESSFUL IT-21 AND WINTEL IMPLEMENTATIONS

1. Hardware

Based on the results in Chapter V.A.3, a system can be built that is based on the Wintel platform, IT-21 compliant, and suitable for training the tasks of map interpretation and terrain association. Using high-end graphics cards, a multi-screen implementation can be utilized to take advantage of a wide field of view. Implementations that do not need a wide field of view, such as implementations for a head mounted display, do not need high-end graphics cards. Consumer level graphics cards can be utilized resulting in a cost reduction of approximately $2,500 for the graphics subsystem.

2. Frame Rates

Using the multi-screen implementation described above, the frame rates achieved by MITAVES II are between 9 and 13 Hz. This is acceptable for a graphics intensive multi-screen application since, at these frame rates, users perceive smooth motion.

In single screen implementations, frame rates averaged between 35 and 55 frames per second depending on the graphics subsystem used. It was shown that a consumer level graphics card could render the fastest frame rates in single screen implementations.

B. HIGHER RESOLUTION DATA CAN BE UTILIZED

Increasing the fidelity of the model by using higher resolution data does not hinder MITAVES II ability to train the tasks of map interpretation and terrain association. Since the same basic tools were available from the previous implementation, only the fidelity of the model was changed.

If the same results can be obtained using a low resolution model, why would anyone bother with making a higher resolution model? To answer this, one needs to look at the maps utilized in both MITAVES implementations. The map in the first implementation was computer generated by Corypheaus' Easy Terrain software. This map is not a standard NIMA product. It is more desirable for pilots to train with the tools that they will use in the helicopter. This included the standard NIMA maps. In order to use the standard maps, the resolution of the model needs to be greater so that features depicted on the maps are also included in the terrain model.

C. MITAVES II CAN NOT BE USED AS A TEST FOR THE TASK

Based on the results shown in Table 3, MITAVES II can not predict how a student will navigate in the air. The results generated from the MITAVES II system do not correlate to the results of the grade cards. Top performers in the air were not top performers in the trainer.

It is advantageous to identify a ground based task that can predict the ability to navigate in the air. If students are tested prior to their navigation training flights, then an instructor can focus on a student's weak areas rather than waste time training a task that the student already knows how to do.

Once a test for the navigation task is identified, modifications of the MITAVES system can be made and evaluated for their effectiveness. Based on test task evaluations, if subjects perform well in the modified trainer, then they will also perform well in the air. An experiment is proposed in the future work chapter that may validate the MITAVES II system as a test task.

D. MITAVES II IMPROVED AIR NAVIGATIONAL PERFORMANCE

Based on the results shown in Table 3, it was proven that MITAVES II was successful in training the tasks of map interpretation and terrain association. Students who used the trainer earned higher grades compared to students who did not use the trainer. It is also the opinion of the instructors at HS-10 that MITAVES II is an invaluable tool for training the navigation tasks.

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VIII. FUTURE WORK

A. EXPERIMENT TO FIND A TEST TASK

Based on the results of the experiment described in Chapter V.3, the MITAVES II system can not predict the performance of students' navigational ability in the air. Further experimentation needs to be done in order to find a ground-based task that can adequately predict how a student will perform the tasks of map interpretation and terrain association in the air.

One proposal would be to use 20 students from HS-10 as the subject pool. They would then use the MITAVES II system as described in Chapter V. After students' initial training on MITAVES II and before their first navigation flight in the helicopter, students would be evaluated once again. This intermediate evaluation would be flown on the trainer with none of the additional tools available for map interpretation instruction. The students would merely be flying through the VE with the paper map as the only tool available to ensure successful navigation of the route. An instructor would be present with the student and together they would fly a simulated navigation flight using the trainer. Instructors would give the same navigation cues and instructions as they do in the air. After the simulated flight, the instructor and the student would then fly the navigation flight in the helicopter. Instructors would evaluate both the simulated and the real navigation flights using the grade cards shown in Appendix A. Based on the instructors' evaluations, if the students' performances in the trainer and in the air are similar, then the MITAVES II system would then be validated as a tool for predicting navigational performance in the air.

B. ANIMATION

1. Route Preview Work

The possibility of watching the route being flown from a first person perspective, before actually flying the route, was explored. MultiGen-Paradigm's Inc. Vega NT software offers pathing and navigation functions however when these tools were used, Windows NT would crash. Because of this, the animation was created by moving a VRML viewpoint (Figure 14) using Cosmo Software's CosmoWorlds. MultiGen's Creator software was used to export the terrain database from OpenFlight to VRML. The terrain database's satellite imagery texture was replaced by a texture consisting of a 1:50,000 contour map of the same area. Creator's "rounded strip face" tool then was used to create thin polygons that followed the route exactly. This route was also exported to VRML. The two VRML models were then imported into CosmoWorlds. The route was manipulated so that it overlayed the terrain in the appropriate area. Then, CosmoWorld's keyframe animator was used to move the viewpoint along the prescribed route.

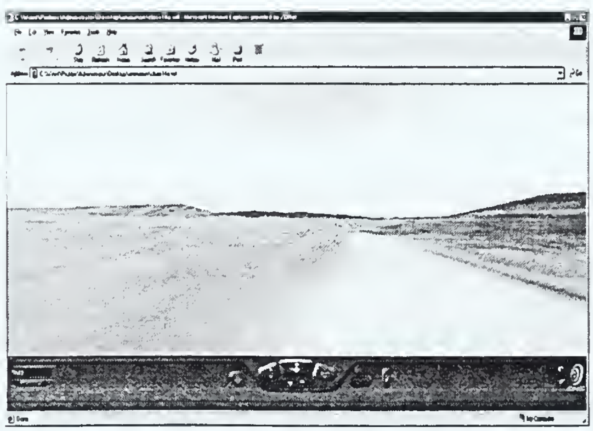

Figure 14. Animation in a VRML Browser.

Using a VRML browser to preview the route before the flight is different from watching a MITAC video because the browser allows the student to interact with the terrain viewpoints. Since a 3D model is used, students can stop the browser and change the viewpoint from egocentric to exocentric. This may be useful for increasing spatial awareness.

Further experimentation is needed to determine the speed that the viewpoint should be moved through the terrain for optimal training transfer. If the viewpoint is moved at 90 knots through the terrain, the student would become bored very quickly because the terrain seems to be moving very slowly at this speed. However, if the terrain is moved at a much faster pace, the terrain would move by so quickly that the student would not be able to pick up key landmarks needed for future use in navigation through the same area. Further experimentation would also determine if watching a preview of the training route before navigating it is beneficial at all. It would need to demonstrate that students who watched a preview of the flight performed better than students who did not.

2. Playback from Saved Files

It also needs to be determined if watching a playback of the student's progress through the route would help the student to see where mistakes were made. For example, a batch file that creates a VRML position and orientation interpolator can be assembled from the data file that MITAVES II creates. The X, Y, Z, H, P, R, and velocity data can be used to create the interpolators. The interpolators would then control the viewpoint as the animation progresses. This would play back the exact path that students flew while they were trying to navigate the route. The playback would consist of a series of gates that would be formed along the correct route. During the playback, if the route were

progressing through the center of the gates, the student would be on the correct path. However, if the student's route was not moving through the predetermined gate path, one could pinpoint the exact location at which the mistake was made. Using the map, the student can then, from a first person viewpoint, determine why the incorrect path was chosen and why the terrain was not interpreted correctly. Once again, it needs to be shown that students who use a playback tool perform better than students who do not.

C. 3D GLASSES

The possibility of introducing 3D glasses is very exciting. Intergraph's Wildcat 4000 video cards come equipped with a standardized stereo output port. Using Stereographic's Crystaleyes 3D glasses (Figure 15), viewing the terrain in stereo is possible. Paradigm's Vega software is stereo enabled. Intergraph's video drivers and monitors are also stereo capable. By choosing the appropriate settings, a refresh rate of 120 Hz can be utilized. The monitors could then be set to an interleaved mode so that both the odd and even scan lines are refreshed at 60 Hz. When the odd and even lines on the monitor are updated separately, a stereo image is created.

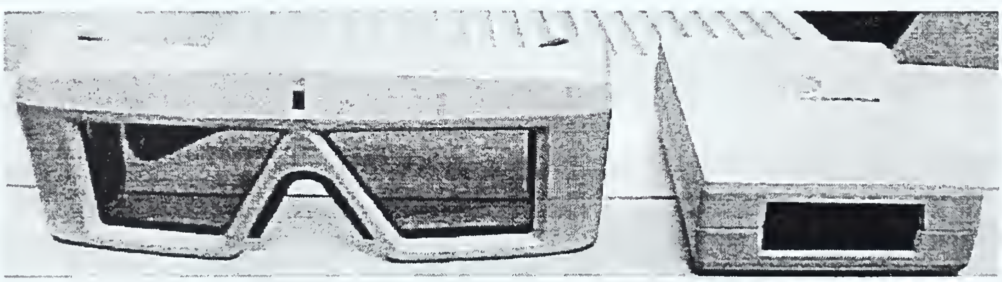

Figure 15. StereoGraphics CrystalEyes System.

The stereo glasses are LCD shutter glasses. An infrared signal is emitted by a small box that is connected to the stereo out port of the graphics card. The IR signal triggers the glasses to make the appropriate lens dark so that only one eye views the

image on the monitor at a time. By shuttering the glasses so that one eye views the odd scan lines, and the other eye views the even scan lines, it is possible to see an image in stereo. Experiments can determine if navigational performance is enhanced by using a VE that is rendered in stereo versus using a non-stereo VE. When viewing the terrain in stereo, terrain features do not seem to pop out in three dimensions as well as viewing common objects. For example, the main rotor blades of a helicopter seem to come out of the screen when viewed in stereo, however, terrain features such as fingers or bases of mountains do not seem to come out of the screen. This can be due to the satellite imagery not having enough contrast in the texture itself. Further experimentation can determine if a detail texture needs to be added to get the appropriate stereo effect.

Viewing a terrain database from the top down with a contour map as the applied texture may also render an acceptable stereo image. Coupling this viewpoint with a force feedback device for the hand, can simulate a raised plastic terrain model and allow better visualization of the terrain and the contour lines that represent that terrain. One application of this would be to quickly toggle between the satellite imagery and the contour map textures to allow for better map interpretation.

D. FIELD OF VIEW

It still remains to be seen which field of view configuration is optimal for terrain interpretation. Several field of view configurations are possible and easily configurable. The current configuration is three 24-inch "wide aspect ratio" screens. Experiments need to be conducted using the following configurations to see which is optimal for the task of terrain interpretation. If it can be shown that using three standard 21-inch monitors is just as effective as three 24-inch wide aspect ratio monitors, then the cost for monitors would be reduced by 50%. Adding a fourth monitor is possible but is not recommended. By

adding a fourth monitor, as shown in Figure 16, a natural seam between monitors is created at the center point of the viewing area. This forces the viewpoint to one of the two middle monitors and thus the student's viewpoint would be constantly skewed.

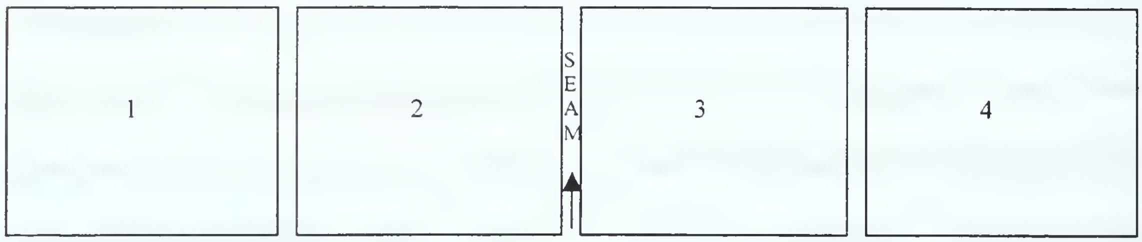

Figure 16. A four screen representation forces a user to look at either screen 2 or 3.

To alleviate this problem, a wider 28-inch aspect ratio monitor could be added that replaces the two middle monitors in the four-screen configuration. Thus, a wide field of view is maintained and there is no middle seam to contend with as shown in Figure 17. However, adding the 28-inch monitor considerably increases the costs for monitors. It also reduces the deployability of the system by increasing the footprint of the whole system.

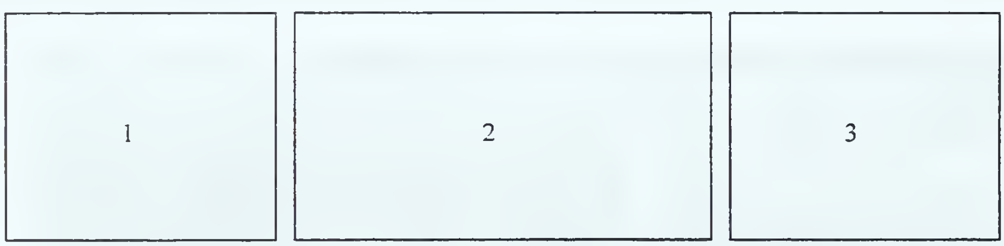

Figure 17. An Implementation with a Wider Center Screen.

One way to decrease the footprint of the system is by replacing the monitors with a single projector. Experimentation can determine if a projected image on a wall can be as effective as a multi-monitor configuration. Finally, it still needs to be determined if a single screen configuration is as effective as a multiple screen configuration.

E. INTERFACES

It still remains to be determined which human-computer interface is the optimum for controlling the virtual helicopter. A PC joystick with twisting capability in the stick and a throttle in the base was used for the current configuration. The current joystick also has four buttons on the base for controlling the zoom factor in the map and bird's eye views, and four buttons and a hat switch on the stick itself. Conventional wisdom is that since we are targeting helicopter pilots as the main users of this system, and helicopters are flown with a stick as the cyclic, a PC joystick is the logical choice for the HCI. However, just about any PC input device would lend itself for experimentation. An intriguing choice would be the Nintendo 64 style game pad. This choice would be interesting to explore because by substituting a game pad for a joystick, all conventional aviation style interface stigmas associated with flight would be removed from the system. The user might get the impression that MITAVES II is more of a navigation trainer vice a flight simulator if there were no aviation paradigms associated with the trainer. By removing the aviation paradigm, MITAVES II will become useful for a wider audience. But more importantly, by removing flight simulator references, the student can concentrate on learning the navigation task vice learning to fly a helicopter.

F. VOICE ACTIVATION

An argument can be made that since the navigation task is delegated to the non-flying pilot in real life flight, the user of the system should not have to try to perform the navigation task and fly the helicopter in the trainer at the same time. One way to eliminate this input device question is to incorporate speech recognition into the system. Using third party software, this would seem to be an easy task to accomplish. The ability of speech recognition software to perform adequately has improved and is quickly

becoming mainstream in the PC world. In the helicopter community, there is a standardized vocabulary for navigation and terrain flying. As the non-flying pilot navigates from the map, he needs to communicate to the flying pilot specific instructions for the maneuvering of the helicopter. These standardized commands could be used to maneuver the helicopter in MITAVES II. For example, the term "come left" would turn the helicopter to the left and the term "stop turn" would roll out the helicopter, stopping the turn. Using this interface would most closely resemble the actual task of navigation in the helicopter during real life missions and training. It would also serve to teach the student the correct vocabulary for terrain flight.

G. SOUND

Experimentation with sound can be accomplished to determine if ambient helicopter noise plays a role in the navigation task. It remains to be seen if the addition or removal of sound, and the level of presence associated with this sound, affects the performance of the navigation task. Currently, the ambient noise of a Bell Jet Ranger helicopter is played continuously through the simulation. Experimentation can determine if changing the helicopter sound from the Bell Jet Ranger to the SH-60 (since that is the helicopter HS-10 pilots fly) would make a difference in performance while the student is navigating in the helicopter. It can also be determined if turning off the sound when any of the available training tools are used affects the way the student perceives the role of the trainer during the navigation task. Maybe turning off the sound would inform the student that these tools are not available during real flight in the helicopter and thus lessen a dependence on these tools.

Spatializing the sound during exocentric views may also have an effect. For example, if the sound fades out as the viewpoint is pulled away from the helicopter, or if

the sound is rotated in the direction of the helicopter as a rotation takes place in the exocentric view, it may be shown that navigational performance increases due these spatialized sound cues.

H. ON COURSE CUES

One can experiment with giving students unprompted cues as to whether or not they are on course during the flying portion of the simulation. For example, if students are flying the route and they are on course, then no additional unprompted information will be given. However, if the student wanders off the course by a set distance, for example 100 meters, then the subject would receive an unprompted cue to check the map. The unprompted cue could be verbal by playing a wav file at the appropriate time, or it could be visual by changing the color of the HUD or displaying the words "CHECK MAP" conspicuously on the screen. By immediately giving an unprompted cue when the student is off course, compound mistakes by the student are avoided. That is, incorrect interpretation of the terrain is avoided if students think they are on course, when in fact, they are not. When the unprompted cue is given, students can immediately bring up the map to determine their mistake, correct it, and continue the learning process. Because training of the navigation task is halted when the first mistake occurs, the learning process would be halted if this cue was not given. If the student continues to navigate after a gross error, then the student is not interpreting the terrain correctly and negative training transfer may occur. Code was written to try to implement this feature into MITAVES II however it only worked part of the time. The problem with the code is that the resolution of the data points that make up the training route was not high enough. While making the routes, data points for the routes were captured roughly every three seconds. It is possible to compare the student's current x, y, and z position with the

position saved in the route data file. However, since the route was made by saving data points every three seconds, holes were encountered where, even though the student was on the route, there was no saved data point in the route file that could verify this. The function would then send out a false negative stating the student was off the route when, in fact, the student was actually on the route. Increasing the resolution of the route data file by collecting points at intervals smaller than every three seconds, for example, every half a second, may help the function return less false negatives. But increasing the resolution of the data file obviously increases the number of data points and also the size of the file. Since the function that checks to see if the student is on the route has to read every single data point in order to make a decision, this process could take long enough to slow the frame rate of the simulation. Since current frame rates are between 9 and 13 Hz, a decision was made not to pursue this feature any longer.

I. FALCON VIEW

Navy Portable Flight Planning Software (N-PFPS) is a collection of full featured flight planning applications that can either work autonomously or as a single integrated program. Falcon View is a part of this suite of programs and is a graphical point and click route planning program. By combining digital maps or imagery with geo-referenced overlays (airfield, naviad, airspace, drawing, and threat etc.), Falcon View presents the aviator with a clear graphical depiction in which to plan a route of flight. Navy, Marine Corps, and Air Force squadrons are using N-PFPS extensively to plan their routes because the software is relatively easy to use and comes built in with the features aviators need most for flight planning purposes. One feature that is lacking is the ability to preview a route in three dimensions. Currently, only two-dimensional representations of the route on the map or on imagery are available. The next logical step is to process

the routes made with Falcon View and incorporate them on 3D terrain, allowing the aviator to preview the route in order to see how a low altitude flight path may be affected by terrain. MITAVES II and Falcon View both use common data formats so the realization of this feature is not far off but significant work would need to be accomplished. After planning the route in Falcon View, an additional program must generate the three dimensional terrain covering the area of the route. It may be possible to use a batch file with command line instructions that MultiGen's Creator software can interpret in order to generate the terrain. It would also be necessary to create RGB images from vector format CADRG and CIB5 imagery for the map and terrain skin textures respectively. If this could be accomplished through batch processing of the data that Falcon View already uses, then automatic terrain generation and viewing could be realized using the MITAVES II interface. After this is accomplished threat domes could be added to give the aviator an even better visualization tool for mission planning.

J. CULTURAL FEATURES

When teaching terrain navigation to students, an emphasis is made on not using man made features. This is so a dependence on features that could change, be moved, or otherwise destroyed is never developed. Since mountains and other terrain features are generally permanent, skills that are developed using only these features are preferred. However, in practice, pilots do use cultural features when they navigate. Experimentation to see whether a terrain model with cultural features such as power lines, towers, major buildings, dams, roads, and water features such as lakes, rivers, and streams, needs to be accomplished to see what role they play in training the navigational task.

K. AUTOMATIC ROUTE GENERATION

Currently there are only four routes for students to choose from when using MITAVES II. An interesting idea is to generate routes automatically and randomly. This would eliminate any route memorization problems that may be experienced by users who train on MITAVES II extensively. An algorithm would need to be developed that could trace a TERF route on any terrain. TERF routes generally follow the path of low terrain so helicopters can avoid being seen and heard by the enemy, so the algorithm would have to analyze the DTED data somehow and come up with an appropriate route. Once the route is generated, a 1:50,000 contour map must be printed with the route on it so the student can use the map for the navigation task.

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APPENDIX A. GRADE CARD

AC-17 SUPPLEMENTAL GRADE CARD

Overall Terrain Navigation Performance

BA AA

Estimated Number of Errors
(Misidentified features, check points, wrong turns)

Error Recovery

BA AA

Terrain Feature Identification

BA AA

Value of Terf Nav Training Time/FRP Progress

BA AA

Comments:

TERF EVALUATION CRITERIA

Overall Terrain Navigation Performance:

BA: Relied heavily or entirely on DR techniques.
Spent a significant amount of time lost
Had significant difficulty maintaining orientation

AA: Correctly identified terrain features necessary to maintain track
Arrived at checkpoints within ±30 secs

Number of Errors

Wrong turns. Misidentified critical features. Required correction by IP

Error Recovery

BA: Required significant time and guidance to regain orientation.

AA: Regained orientation with minimal cues.

Terrain Feature Identification

BA: Required significant time/help to identify critical features

AA: Consistently relied on terrain features to maintain orientation

Value of Time/Student progress

BA: Spent significant amount of time on fundamental skills
FRP overwhelmed with navigation, little time for other tasks
Marginally improved navigation skills

AA: Showed significant improvement in navigation skills

Comments:

Any additional comments relating to student's performance or terrain navigation training in general.

Figure 18. AC-17 Supplemental Grade Card.

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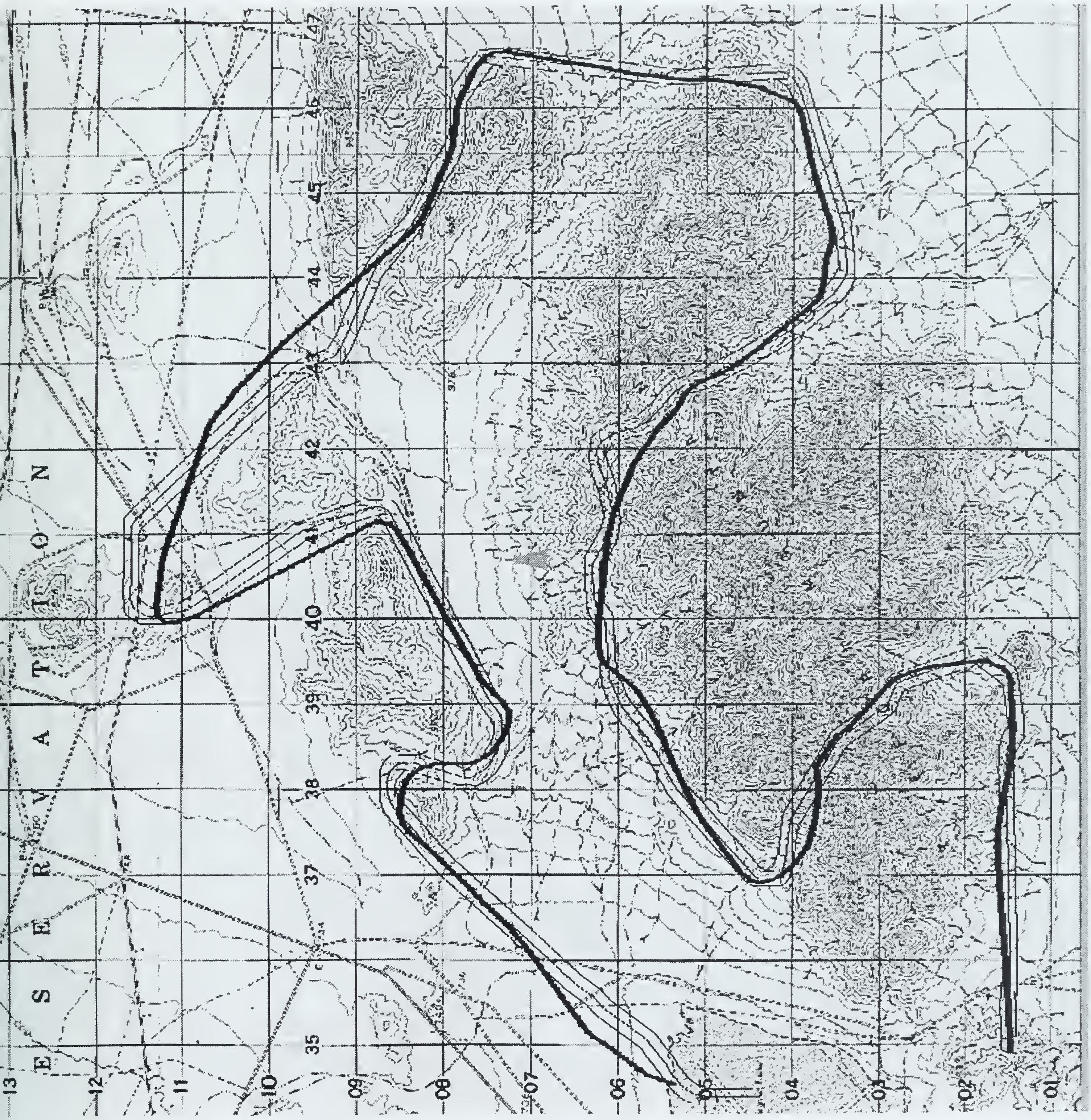

Figure 19. Route data for Subject 1.

APPENDIX B. SUBJECT DATA

FRP name: Subject 1

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

|————————|————————|————————✔————————|

Number of Errors: 1

(Misidentified features, check points, wrong turns)

Error Recovery:

BA AA

|————————|————————|————————✔————————|

Terrain Feature Identification:

BA AA

|————————|————————|————————✔————————|

Value of Terf/Nav Training Time/FRP Progress:

BA AA

|————————|————————|————————✔————————|

Comments: Subject 1 also did an AA job on his nav. He did a good job of reorienting himself after becoming lost the one time. Also did a nice job of terrain identification.

APPENDIX B. SUBJECT DATA

Figure 20. Route data for Subject 2.

APPENDIX B. SUBJECT DATA

FRP name: Subject 2

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 0
(Misidentified features, check points, wrong turns)

Error Recovery: N/A – Found all check points
BA AA

|————|————|————|————|

Terrain Feature Identification:
BA AA

|————|————|————|————✔|

Value of Terf/Nav Training Time/FRP Progress:
BA AA

|————|————|————|————✔|

Comments: Subject 2 didn't get lost once. He remained oriented throughout. Never got lost so did not have a chance to observe reorientation process. Subject 2 did probably the best nav I've seen for a CAT I student.

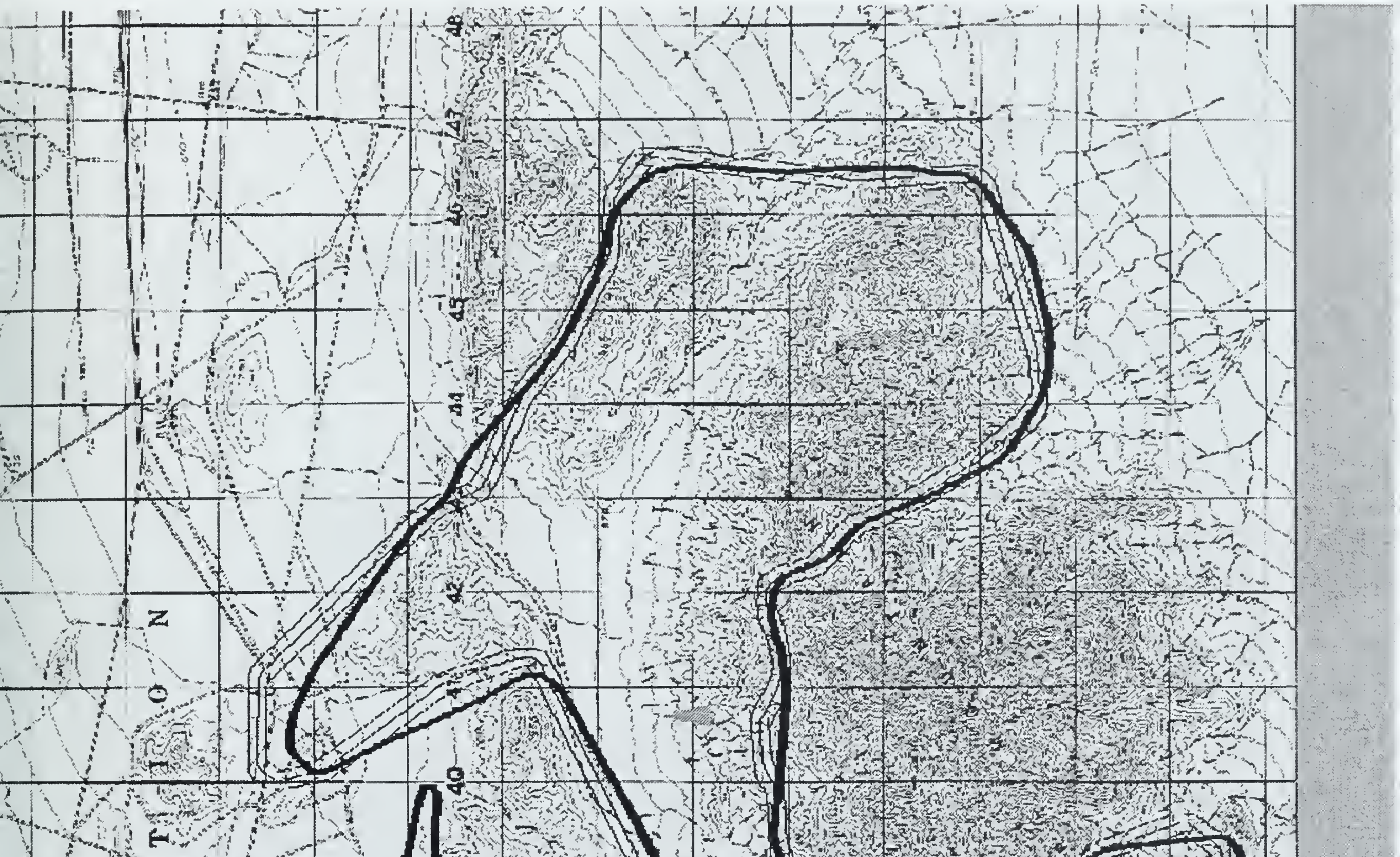

Figure 21. Route data for Subject 3

APPENDIX B. SUBJECT DATA

FRP name: Subject 3

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

|————|————|————✔——|————|

Number of Errors: 2
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|————|————|———✔———|————|

Terrain Feature Identification:
BA AA

|————|————|———✔————|————|

Value of Terf/Nav Training Time/FRP Progress:
BA AA

|————|————|—————✔————|

Comments: Subject 3 did an average to above average job on his nav. Generally, he knew where he was and could identify terrain features fairly well. He got off track a couple of times but managed to get back on his route with minimal cues. Overall, the training we were able to get was above average for a CAT I RP.

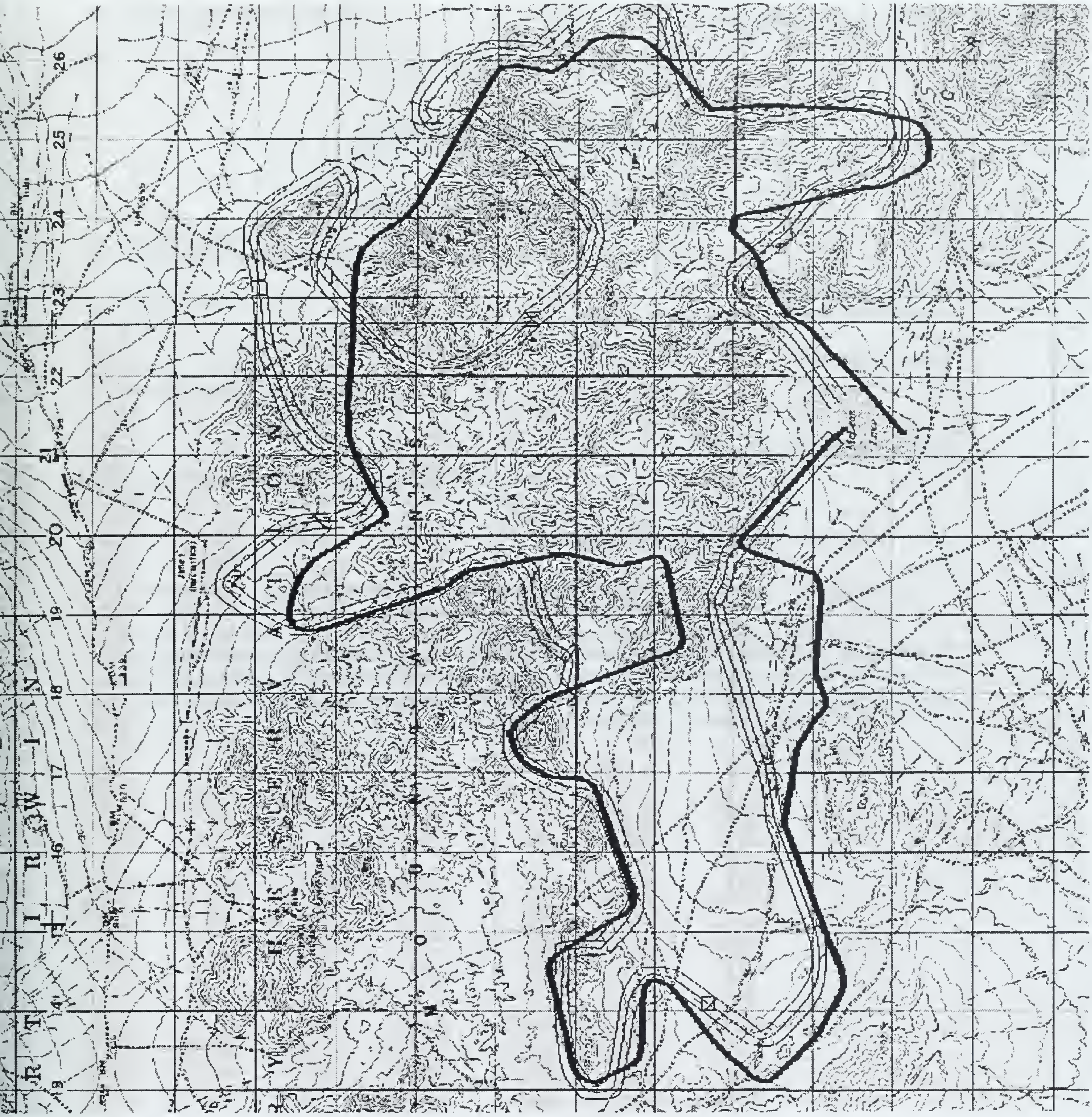

Figure 22. Route data for Subject 4

APPENDIX B. SUBJECT DATA

FRP name: Subject 4

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

✔————————|————————|——————————|————————|

Number of Errors: **6**
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|————————✔————————|——————————|————————|

Terrain Feature Identification:
BA AA

|————————✔————————|——————————|————————|

Value of Terf/Nav Training Time/FRP Progress:
BA AA

✔————————|————————|——————————|————————|

Comments: Subject 4 struggled with his navigation. He consistently got off track and was unable to distinguish geographic features along the route of flight. Subject 4 also needed a significant amount of direction to get reoriented. Definitely BA performance when compared with CAT I RP's who have not used the computer program.

APPENDIX B. SUBJECT DATA

FRP name: Subject 5

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 2
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|——————|——————|——✔————|—————|

Terrain Feature Identification:
BA AA

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Value of Terf/Nav Training Time/FRP Progress:
BA AA

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Comments: Overall a pretty average event for a CAT I student. Subject 5's navigation was slightly below average but was buoyed by the fact that when he did get lost, he did a decent job of getting back on track. Subject 5 got lost due to difficulty in terrain identification. Once the feature was pointed out to him he could correlate it on the chart, but until that time he was a bit clueless.

APPENDIX B. SUBJECT DATA

FRP name: Subject 6

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 4

(Misidentified features, check points, wrong turns)

Error Recovery:

BA AA

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Terrain Feature Identification:

BA AA

|——————|———✔———|———————|—————|

Value of Terf/Nav Training Time/FRP Progress:

BA AA

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Comments: Subject 6 had a below average flight particularly in the navigation department. She struggled with identifying terrain features which led her to difficulty in her overall navigation effort. Due to her struggles she needed quite a bit of hints to reorient herself.

APPENDIX B. SUBJECT DATA

FRP name: Subject 7

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 2
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|———————|———————|—————✔———|———————|

Terrain Feature Identification:
BA AA

|———————|———————✔———————|———————|

Value of Terf/Nav Training Time/FRP Progress:
BA AA

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Comments: Subject 7 had an overall above average event. He only got lost twice and each time managed to get back on track without too much prompting. His terrain identification was about average, and the times he couldn't identify a terrain feature were when he would get a little flustered and lost. This only happened twice, though, and as the flight progressed he did improve. Overall, the training time was pretty well spent.

APPENDIX B. SUBJECT DATA

FRP name: Subject 8

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 4
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

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Terrain Feature Identification:
BA AA

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Value of Terf/Nav Training Time/FRP Progress:
BA AA

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Comments: Subject 8 was a CAT 5 student who had not flown the H-60 before he came to HS-10 and had never flown over-land type events. Even though he was a CAT 5 he struggled quite a bit with his navigation. Going up to Camp Pendleton he got lost a couple of times and during the 1:50K navigation, he really had a hard time identifying checkpoints even when they were pointed out to him. Due to his inability to identify terrain features, he seemed to get lost fairly easily even when he was using DR methods. Error recovery was also hindered by an inability to identify terrain features. Overall, the entire navigation evolution was below average and it really hindered his training overall.

APPENDIX B. SUBJECT DATA

FRP name: Subject 9

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 2
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|-------------|-------------✔-------------|-----------|

Terrain Feature Identification:
BA AA

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Value of Terf/Nav Training Time/FRP Progress:
BA AA

|-------------|-------------✔-------------|-----------|

Comments: Subject 9 had an overall average flight. He stayed fairly well oriented and could usually identify his checkpoints although he sometimes had to fall back on his DR techniques. Although he did miss a couple of checkpoints, he managed to get back on track with a little help and didn't lose too much time on the route. Terrain feature identification was a little weak led him to get lost the two times. As the flight progressed his navigation did improve so the training time was useful.

APPENDIX B. SUBJECT DATA

FRP name: Subject 10

TERF EVALUATION RESULTS

Overall Terrain Navigation Performance:

BA AA

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Number of Errors: 2
(Misidentified features, check points, wrong turns)

Error Recovery:
BA AA

|————|————✔————|————|

Terrain Feature Identification:
BA AA

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Value of Terf/Nav Training Time/FRP Progress:
BA AA

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Comments: Subject 10 did an above average job of navigating. He was better at maintaining his orientation than the average CAT I student. Subject 10 struggled a little to reorient himself when he got lost. Took some prompting to regain his position. Overall Subject 10 did a nice job. He was able to identify 90% of the checkpoints and surrounding terain features. AA overall when compared to average CAT I students.

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